

Friday, March 19, 1886.

GENERAL J. T. WALKER, C.B., F.R.S., &c., Member of Council,
in the Chair.

THE WELDON RANGE-FINDER.

By Colonel J. B. RICHARDSON, R.A.

UNTIL the fire of infantry and artillery approached something like accuracy, instruments which would indicate with precision and speed the distance of the object aimed at were unnecessary. For some years past the artillery, however, have been aware of the immense increase both in the moral and actual results of their fire when the range is known beforehand. It is true that they can make use of trial shots, but the judgment of the unaided eye is singularly incorrect when estimating the position of even so distinct an object as the burst of a common shell at a moderate range, while the strike of rifle and machine-gun bullets is in most cases indistinguishable. As a consequence, artillery have been the first to welcome each advance in range-finding, and the earliest steps towards supplying the want felt came from that branch. The range-finders first introduced into the Service were the inventions of two artillery Officers, Nolan and Watkin, and these still remain Service instruments.

Infantry were trained mainly to shoot at targets on well-measured and marked ranges, and as a consequence did not so soon recognize the want of an accurate range-measurer as did the artillery, whose batteries, especially in India, seldom used targets on measured ranges, and more frequently practised at gun-pits, shelter-trenches, and dummies at unknown ranges. The development of field-firing has, however, led to the demand for a trustworthy and handy range-finder for infantry, and the new Service instrument which I bring before you to-day comes from the infantry. It was the want of a range-measurer adapted to the wants of his branch of the Service that primarily induced Colonel Weldon to turn his attention and ingenuity to the invention of a variety of instruments which have resulted in the simple range-finder before you, which is excellently adapted for the field work of both artillery and infantry. While simple, rapid, and accurate in working, it is capable of standing the very severe tests of varying climates, and of the rough usage inseparable, at any rate with mounted corps, from the use of a range-finder in the field.

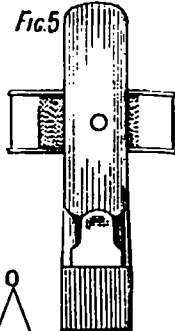
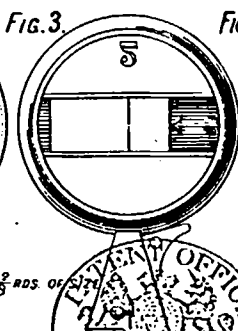
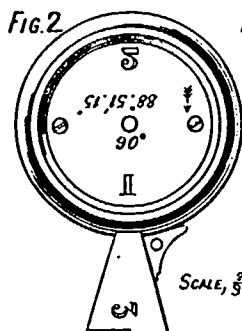
An early form in which Colonel Weldon brought forward his range-finder deserves passing notice. It was something in the nature of an optical square, the glasses, however, being set at an inclination to reflect an angle of $88^{\circ} 34' 3''$. The instruments were remarkably accurate, easy to use, and possessed the desirable capacity of finding the range of moving objects with very considerable precision; the distance of the puff of smoke from a rifle was fairly accurately told by their use. There were many methods of using them, but the general system can be easily understood by a reference to Fig. 1, where an observer A, moving to his right or left, reflected the object O on B; the angle $OAB = 88^{\circ} 34' 3''$. The observer B moved forward or backward on the line BA until he saw in his glass the object O reflected on A; the angle OBA being also $= 88^{\circ} 34' 3''$. An isosceles triangle was thus formed, of which the base was to either side as 1 : 20. The base was generally paced, which was found to yield sufficiently accurate results, but it was measured if extreme precision was required. Ranges were found by trained men with remarkable rapidity, ease, and accuracy with these instruments, and they were very portable; but, while they were void of most of the defects of the Service range-finders and were effectively used on service in Afghanistan, they possessed two defects in common which appeared to their inventor to render them imperfect, viz., they could get out of adjustment, and the glasses were affected by climate. They did not easily get out of order, but were decidedly difficult to readjust if they did.

The present Weldon range-finder combines all the advantages of these early inventions, while it is free from their defects, and possesses many merits peculiar to itself. Short of getting crushed, it cannot get out of adjustment, and the silvering difficulty has probably been overcome. Exposed to severe tests, none of the new prisms have shown signs of deterioration. Figs. 2, 3, 4, 5 are representations of the instrument in various positions: you can see that it is very portable and very simple.

It consists of three triangular prisms of a specially-made hard crown glass, entirely free from blemishes and striæ. The prisms are silvered on one side by precipitating silver from a solution on the glass, varnishing, and further protecting them with several coats of a special paint, or by a layer of copper electro deposited on silver. The prisms are cemented to the frame with a cement that is impervious to damp; but even supposing the silvering destroyed it could be removed altogether and the prisms would still reflect. The two larger prisms are cemented to a bar between two circular discs of thin metal, forming what has been termed the "prism block;" and the smaller prism is similarly fixed in the handle of the ring case, in which the prism block revolves on pivots. In addition to the cement the prisms are secured from movement by small pins. The case ring, block, &c., have been made of various metals and sizes, ordinarily they are made of brass and are browned.

Colonel Weldon had extreme difficulty in getting the prisms made with accuracy; not only must the apex angle be true, but one of the base angles must be exactly half that angle, and therein lies a

WELDON RANGE FINDER.



SCALE, $\frac{2}{3}$ INDS. OF SIZE

Fig. 6.

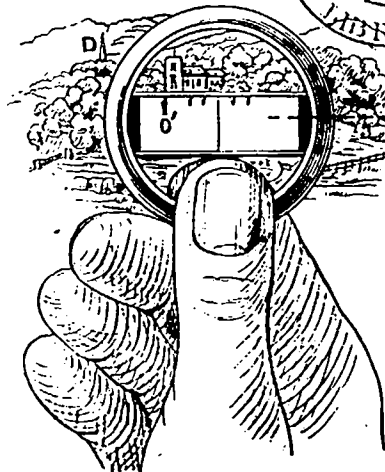


Fig. 1.

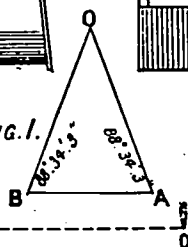


Fig. 8.

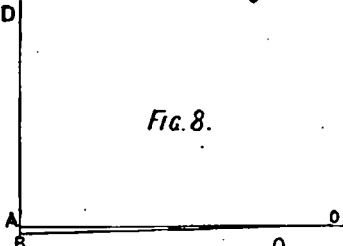


Fig. 9.

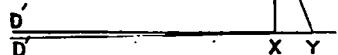
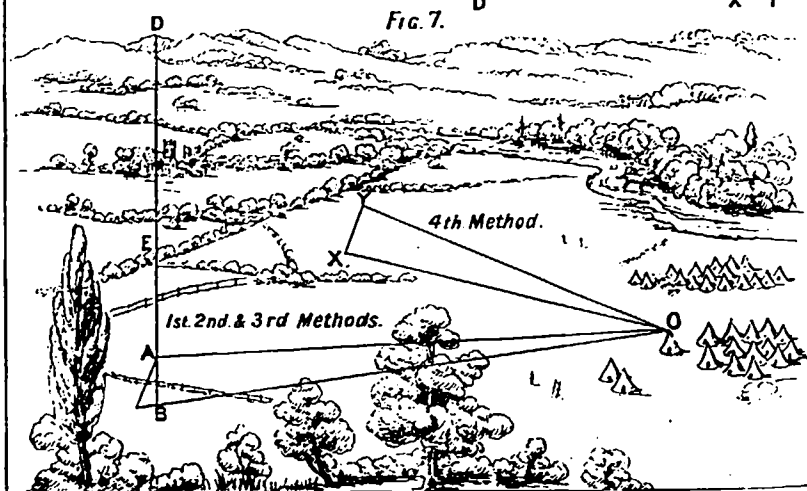


Fig. 7.



difficulty. Their present perfection is the result of patience, perseverance, and costly experiment. Optician after optician, both in England and on the Continent, undertook to make them accurately, but their attempts resulted in constant failure. The method now adopted is a secret.

The angles reflected by the prisms are respectively—

1st prism.....	90°
2nd „	88° 51' 15"
3rd „	74° 53' 15"

The first two are the angles at the base of a right-angled triangle, of which the perpendicular is to the base as 50 : 1. The third with the complement of the second (viz., 91° 8' 45") are angles in an obtuse-angled triangle, of which the side subtending the angle 74° 53' 15" is to the base as 4 : 1.

In prisms of this nature, if the apex is other than a right angle, angles of more than one dimension can be observed towards the corners of the prism. These false angles would of course lead to error, but by shutting off or blinding a portion of the prism, the false angles are eliminated, and the proper angle only can be observed. In the second and third prisms of the instrument these corners are blinded by a small plate of metal (see Fig. 3). An arrow on one of the circular discs (see Fig. 2) shows the corner of the prism, and the direction, in which an observer should look when using the second prism. In the right-angled prism all three corners are available for observation (see Fig. 5). Fig. 4 shows a position of the instrument when using the third prism. This third prism is, in my judgment, of little practical use in field range-finding. It is intended to measure the base formed by the first and second prisms, but it is very seldom indeed that a case occurs in which its employment is absolutely necessary. I think that the range-finding is more accurate without it, and as rapid; except in the instance of very long ranges, say two miles or so. However, it is not in the way, it renders the instrument complete, and its use has the very remarkable property of compensating for errors of observation of the length of base. The third prism with the second gives a triangle of which the base is to the side subtending the angle of 74° 55' 15" as 1 : 4.

A little practice is required to bring the image of any object to the right (or left) of an observer into the field of the prism. With the prism block turned at right angles to the case ring, the instrument is held as shown in Fig. 6, close to the eye, by which a large field is obtained, and only a slight turn of the head or hand is required to bring a fresh field into view, either laterally or vertically. The prism block is steadied by the thumb and forefinger, taking care to leave a space below the corner of the prism, so that objects seen in front by direct vision, either above or below the block, may be viewed simultaneously with objects reflected in the prism. The reflection of an object on one side of an observer is to be looked for in the corner of the prism furthest from the object; thus, the reflection of the man

at O on the observer's right is found at O', towards the left corner of the prism, Fig. 6.

The reflection of an object in any of the prisms can be aligned on any given point seen by direct vision in front, by the observer moving to the right, left, backwards, or forwards. In range-finding, if an observer sees the reflection of O (Fig. 6) fall to his right of a point D, he can bring O immediately under D by moving to his rear if D is far away; or to his left, or diagonally to his left front, if D is near. It is practically best, however, not to try to bring the reflection on any special object seen by direct vision, but to choose a distant object on which the reflection falls true, as in this case on the church tower.

The eye of the observer forms the apex of the angle to which the prism is cut, when objects on either side of an observer appear directly underneath (or above) those seen by direct vision; but to make a correct angle the reflected object should be kept upright and the reflected horizon as level as it is naturally, for if the instrument is held so that the ground reflected appears to slope when it is really level, or *vice versa*, the required angle will not be observed. An observer also must be careful to fix his attention on the far-off direction point, and not on any intermediate object such as a pole, &c., which he has placed as a guide to lead his eye straight to the distant point. This is often neglected at first, and leads to error. This is explained later on.

There are several methods of finding the range of a distant object with the prisms:—

First Method.—One observer using nothing but the second and first prisms in the order named. This appears exceedingly simple, but it requires a vast amount of training and practice. With unskilled observers it is unreliable.

Suppose the range of an object O (Fig. 7) is required. The observer using the second prism at B, reflects O on some distant point D. The angle $OBD = 88^{\circ} 51' 15''$. Selecting any intermediate object, say E, on the line BD, to assist him in walking straight, he paces towards D, stopping to observe at intervals with the first prism, until he arrives at A, where he sees O reflected along the line AD, so that the angle $OAD = 90^{\circ}$. In moving from B to A he has counted every second pace by the simple rule of commencing with the left foot and counting a unit every time the right foot came to the ground. These units of base represent hundreds of yards of range. The greater the excess of BD over BO, the greater the chances of accuracy.

Second Method.—One observer using the first and second prisms, aided by a mark such as a pole, or a man, a sword stuck in the ground, or anything that can be left to mark a particular spot. A specially made pole is the best.

Taking the same figure (Fig. 7) with O as the point of which the range is required, the observer, using the first prism at A, reflects O on a distant point D, and plants a pole at this spot. He turns the prism block so as to have the second prism ready with the blind on the same side as the object, and retires on the line DAB. He stops to observe, facing D; perhaps seeing the reflection O on his right of

D. He has not gone far enough. Suppose he moves too far to the rear, he will see O on his left of D, and must advance; but he quickly finds the point B where O is reflected true on the line of the post at A and the distant point D. Then, as before, the base $BA = \frac{1}{25} OA$, and may either be paced as described under the first method; measured with a tape, on which is marked hundreds and tens of yards of range; or measured by using the third prism, as described under the third method.

In either of the above methods, if a good natural direction point D cannot be found, a pole, or a man with a rifle or stick, may be placed as a direction point, care being taken to place the pole, or whatever else is used, at a distance from A proportionate to the range. Thus, if O is probably about 1,000 yards away, the pole should not be less than 50 yards; if OA be 2,000 yards, the distance point should certainly not be less than 100 yards, from A. The further the distance point the greater the chance of the range found being accurate. It rarely happens that a good natural distant direction point cannot be found on one side or the other, in country where troops are likely to want to know a range.

Third Method.—If it is thought desirable to measure the base AB (Fig. 7) found by the second method, with the third prism, another pole or marker is required. Having found A and B by using the first and second prisms, the observer plants the second pole at B, looks to it one end of a tape on which is marked hundreds and tens of yards of range at every 18 inches, and walking back on the line OB, he arrives at a point C, where the pole at A is reflected along the line BO. Then $CB = \frac{1}{2} AB = \frac{1}{25} AO$. Every hundred yards of AO is thus represented by 18 inches of BC.

This method is introduced to meet the difficulty of measuring a long base AB accurately if the ground is rough, or if obstacles intervene between A and B. Thus, supposing O to be 5 miles distant, BA would be = 170 yards, and it would probably be considerably quicker to use the third prism than to pace or measure the base, but for ordinary artillery or infantry ranges, the base AB is so short, that I think it is quicker and more satisfactory to pace or measure along the base.

Fourth Method.—This is also rapid and accurate, but needs some training. It requires two instruments and two observers, each using the second prism. It adds to the capabilities of the instruments one advantage over other systems of range-finding with which I am acquainted, viz., ease in ascertaining rapidly the range of a moving object. This, as I have said, was a point claimed for Colonel Weldon's earlier range-finders, and his latest instruments retain the advantage.

Turning to Fig. 7, suppose O to be again the object whose range is required, an observer X, using the second prism, reflects O on the second observer Y, moving either to his right or left for the purpose, but not to his front or rear. Y, also using the second prism, moves either forwards or backwards, but never to his right or left, until he gets the reflection of O true on X. Then each of the

angles OXY and OYX = $88^{\circ} 51' 15''$ and $XY = \frac{1}{2} \text{ of } XO \text{ or } YO$. Every 4 yards of the base paced represents 100 yards of range. In practice whenever either observer sees that he has the reflection of O truly on the other observer's instrument, he raises his disengaged hand. When both observers give this signal at the same time the base is found. By this arrangement little difficulty is experienced by trained observers in getting the base, even if O be moving with considerable rapidity. Directly the signal is simultaneous the base is paced, a few seconds sufficing. Neither observer under any conditions requires to move more than $\frac{1}{2}$ of the pace of the moving object.

Little accuracy of result will be obtained by pacing, as described in the above methods, unless an observer is trained in pacing yards. A man can be trained to do so in a very short time, but practice is necessary to keep up the attainment. A plan which has been found very successful is as follows:—200 or 300 yards are measured on some line which chances to be aligned on distinct objects, so that men may be able to march straight along it. At each hundred yards a peg is driven in to the head, so that it cannot be readily seen. For a few yards at each end of the line pegs are also driven in to a level with the ground at every yard. The man paces up and down these minor marks, until he gets an idea of a 36-inch pace, and he then paces from the starting point along the whole line. Commencing with the left foot, he counts the number of times his right foot comes to the ground, and halts when he has counted fifty. If he has paced yards correctly, and walked straight, his right foot should be on a peg, if not, the difference constitutes his error. He soon learns not only to pace yards but to march straight, and to count without effort the number of hundred yards in a range formed by the first and second methods. For the fourth method his counting should run 1.2.3 1; 1.2.3. 2; 1.2.3. 3; counting each pace, and his right foot would be on a peg when he has counted 25.

It has been objected that the base used in the first and second methods is too small for accurate results. Fig. 8 is a figure drawn to scale.

It is impossible for the eye to distinguish the exact point where the lines AO and BO cut one another about O. A base of 1 : 50 appears altogether too small to measure such an apex angle as AOB, and so it would be if the base were found by measurement of two interior angles. It is the attempt to measure the interior base angles of a small based triangle that proves the greatest source of error in most systems of range-finding. When the distance is too short between the eye and the other end of the base, the least lateral movement of either sensibly affects the result. This is easily demonstrated by the following diagram.

Suppose two lines D'Y DY inclined to one another at a small angle. For a considerable distance they appear to run in one line, but the eye detects divergence at X and Y. With XY as a base erect a triangle XOY, and suppose the apex O to be an object of which the range is being taken. The observer at Y in measuring the angle

OYX may be observing either of the angles OYD or OYD', and similarly, if his eye has no further than Y to travel, may observe false angles when measuring OXY. The greater the distance of D and D' from Y, the more easy is the error detected. Lateral error, in fact, creeps in with greater or less ease, according as the base XY is shorter or longer.

Weldon avoids this source of error in a very simple manner by observing one interior and one exterior angle, so that for range-finding purposes his base is from the eye to the far off direction point, which is possibly 10 miles away. Thus in Fig. 9 he uses the angles OYD, OXD'. It is this which enables a simple instrument, devoid of telescopes or other complicated aids to the eye, to obtain such correct results.

Colonel Weldon has some Wollaston's prisms, giving the required angles of reflection, in which light is totally reflected within the prism. Silvering is here unnecessary, and instruments so made are absolutely free from the influence of climate.

The time at my disposal will not allow me to do more than state the general results of official trials of the range-finder. All reports that I have seen have been, with one exception, highly favourable. In nearly all cases it appears to have been tested against Watkin's range-finder, and generally by observers practised in the use of the latter, but to whom the Weldon was a novelty, and who in some instances used it for the first time at the trials. The fact that under these circumstances remarkable accuracy was generally obtained is perhaps the highest testimonial to the efficiency and simplicity of the system. The exception mentioned above was a report from Bombay, which, though on the whole favourable, stated that the Watkin range-finder proved in most instances the most accurate at very long distances; there were no serious discrepancies between them, and it was further remarked that had the observers had as much practice with the Weldon as with the Watkin, the results might have been different. Few of the reports take the time occupied in finding a range into account, yet the great rapidity with which distances can be measured with the Weldon is, combined with its general accuracy, one of its strongest recommendations as a field range-finder.

The chief points urged in favour of the Weldon system in the various reports are:—1st. That it is easy to learn and teach its use. 2nd. Not liable to get out of order. 3rd. Practically accurate. 4th. Compact. 5th. Portable. 6th. Light. 7th. Cannot get out of adjustment. 8th. Serviceable in the field. 9th. When mean of two observers is taken ranges found are as near as possible correct. The only objections I have seen in the reports are:—1. That it is difficult to obtain coincidences in a bad light, or in a very bright light. 2nd. That there is a glare from the metal case, and that the case should be of dull metal. 3. That there is a difficulty of obtaining coincidences, owing to the thickness of metal of prism block.

With regard to the latter, the metal of the prism block is now made very thin. It would be a decided advantage if it could be done away with altogether. The first objection is common to all

range-finders. The second is easily got over by shading the instrument with the disengaged hand.

The most exhaustive, and probably the most accurate, official trials in England were those made at Aldershot. I have not had access to the original papers, but I believe that the following figures are correct as to one series of observations:—

Number of observations.	Ranges measured on O.S. map. Yards.	Weldon. — Error in yards.	Watkin. — Error in yards.	Error per cent. of range.	
				Weldon.	Watkin.
100	163,015	3,390	7,312	1·8	4·0

and it is curious that a long series of official trials in India gave very similar results.

One remarkable observation occurs in the report of trials at Bangalore.

Distance observed by Weldon R.F.	14,350 yards.
„ accurately measured by theodolite	14,400 „
Error	90 „

The distance is over 8 miles.

In some of the Indian trials the average time taken in obtaining measurements of ordinary ranges is given as $1\frac{1}{4}$ minutes. I have myself seen many correct ranges taken in less than 1 minute each, and the distance of moving objects very approximately given in from 35 seconds to 50 seconds, by well-trained observers.

Major A. FEATHERSTONHAUGH, R.E.: When I was in India I saw some observations taken with Colonel Weldon's instrument, and I also saw another instrument used, which was really a modification of the Weldon instrument by Mr. Bolton. It was very much on the same principle. The original base adopted by Colonel Weldon was one-twentieth. There was an official trial made of the Bolton instrument, which, as I said, is very much the same as Colonel Weldon's, before the Commander-in-Chief in Calcutta, and although no opinion was then expressed, the difficulty in the minds of those who had to judge of the subject was that the base was too long. It was only one-fortieth, but it seemed to be very long. It has now been reduced to one-fiftieth, but that is still very long, being 20 yards per 1,000 yards. 1,000 yards is not a very long range now-a-days for artillery purposes, but if you are on the top of a hill, such as you get in Afghanistan, it is very difficult indeed to get 20 yards straight on end in every direction. I should be glad, therefore, if Colonel Richardson could answer that question as to whether even 20 yards per 1,000 is not rather long. My second remark is upon the fourth method of observation, which Colonel Richardson says he finds useful in taking the distance of moving objects. You have two men, one at Y and one at X, taking the distance of the object at O, and that object is supposed to be moving at 5 or 6 miles an hour, or more. If it is a steamer it would be going 10 or 12 miles an hour. These two men have to take

two observations of this moving object, and to manage so that their observations are simultaneous. I should like to ask how is that possible, seeing that they have no communication with each other? How can they arrange to get their observations absolutely simultaneously? It is just as if two men were firing at a partridge, one holding the gun and the other pulling the trigger. I think, therefore, there must be something that is not quite clear about this finding the distance of moving objects by the observations of two men. The only other thing that I would refer to is the last paragraph of the lecture, in which Colonel Richardson mentions a series of observations taken at Aldershot, and out of 100 observations he gives the error per cent. of range with the Weldon instrument as being 1.8. That I suppose is the mean. Those who have had to deal with astronomical observations know that provided there is no radical error in the process you may get a mean of any accuracy you wish by multiplying your observations, because although one observation may be a large distance wrong in one direction, the next observation may show the same error in the other direction, and the result is you get a mean error of a very small amount, whereas the error of a single observation may be very large indeed. It seems to me that for military purposes your first observation should be as accurate as possible, and it is no good saying that twenty other observations taken immediately afterwards would give a small mean error.

Major WHITE: In rising to speak on this subject I may state that I do not come forward in any official capacity. I am, however, instructor in field range-finding to the mounted branches of the Royal Artillery, and at present in charge of the School of Range-finding at Aldershot, and I was Secretary to the Committee on Range-finders from 1879 to 1891, so that I have some experience in these matters. Now, I think, that too much attention is paid to the range-finder and too little to range-finding. It is as if the whole of a discussion on musketry were to be devoted to the particular rifle used, and not to the shooting. A great deal depends on the way in which an investigation of this kind is conducted, for while no doubt various instruments have various merits, one is often better than another for a particular purpose. Colonel Richardson has brought forward this range-finder as an infantry instrument, and therefore I cannot say so much about it. The infantry know their own requirements best. Of course an individual soldier does not take the range to each opponent he aims at; but no doubt in the field if you got a large body of infantry or cavalry *stationary*, and you wanted to fire at a long distance which you could not measure by the eye, then the aid of the range-finder might be important, and in that case an instrument which gave *approximate* accuracy *with rapidity* would undoubtedly have a great advantage over one which gave the greatest accuracy but with some loss of time. I have myself carried out a number of trials with the Weldon range-finder, and with instruments identical in principle,¹ and I have seen the reports of other trials. The result I find is that it will take the range with approximate accuracy and considerable rapidity. I do not know the exact comparison, but it will take it quicker than the Watkin range-finder, because a much shorter base is used. The time occupied in taking the range with the Watkin range-finder is that taken up in running over the base and back again by the range-taker in addition to the time needed for the two observations, which you may say is one minute for a long range, and half a minute for a short one; thus with the Watkin range-finder up to 1,000 yards we allow two minutes per range, and as we increase the ranges we increase the bases, and therefore the time, until when we get to 6,000 or 7,000 yards we allow as much as six minutes per range; but of course very long ranges would only be taken for artillery purposes, and under circumstances in which spending five minutes or even a quarter of an hour more or less would not very much matter. It would be the case of engaging an enemy which had fixed positions at great distances, and where it was of the greatest importance to get an accurate range within 100 yards or less. With regard to the Weldon range-finder, it undoubtedly finds the range quickly if it finds it at all, but it has the disadvantage that there are many places where it is altogether inapplicable. You are tied down to a certain base, and you may find that

¹ Mr. Erskine Scott's range-finder; the Steiner range-finder; the Edwards range-finding system.

it lands you in a pit, or a hedge, or the middle of a wood, or it runs you down the side of a hill, and you cannot see the auxiliary object that you have to line yourself on. What you want is to be able to put down a marker at any point and take the range from *that* point; it is no good finding the range from somewhere else when time is an object; that may be very useful, but you have to consider the time lost in making the correction. That is a disadvantage constantly met with when you are dealing with lumpy ground—I won't say hilly ground—because you may get very good ground for the Weldon instrument in a hilly country; you may get slopes giving you plenty of base; you may see your object in whatever direction you go, and you may get distinct auxiliary points. It is, however, a very great tie to be compelled not only to see your distant object from your own pickets at each end of your base, but also to find something to your right or left to work upon. There are many cases where you cannot find the range on account of the proportional base. You think you are going to get it, but a house comes in the way or a tree, or something just at the point where you ought to make your second coincidence, and then you have to begin *de novo*. I think on the whole, however, that these instruments may be made very useful, and we are very much indebted to Colonel Weldon for what he has done so far. There was no doubt a difficulty at first in getting the prisms properly cut, but the Service specification allows a liberal margin for their accuracy; it actually allows two different instruments to have a plus or minus error of 2½ per cent., that is, a difference between them which would amount to 5 per cent. difference of range (5 yards per 100 yards), though the variation would rarely of course come up to that. That is the Weldon. The first Watkin instruments were given to the regiments for use, but the men were not shown how to use them. The result was they broke them very quickly. It was very much as if you had started a telegraph, and sent your instruments and wires down to various regiments, and said, "There, that is a nice telegraphic apparatus; let Tommy Atkins use it." The result would be, no doubt, that he would break it. It was the same with these range-finders, and I am not at all surprised that they could not take a range. But now-a-days we have established a school of range-finding. We take our non-commissioned officers of Horse and Field Artillery and put them through a very severe course of training. If, at the examination, their average work shows inaccuracy exceeding 4 per cent. in the range, they do not get a certificate. If it is better than that, they are marked "good," and if the error is less than 2 per cent., they get "very good;" and out of a class of about twenty, there are often two, sometimes three or more, who get "very good."¹ So much for the Watkin. It is a very good instrument, and there is not much fault to be found with it. Nevertheless, you can get approximate accuracy with greater rapidity sometimes if you use the Weldon, and for infantry purposes they want very rapid methods without much trouble in learning. With regard to the use of the instrument, however, there is one great difficulty. You *must* hold it in the plane of the objects, and this is not an easy thing to do when they are not in the horizontal plane. The result of our first trials at Aldershot was this:—They showed that if men were well trained they could use the Weldon instrument very well, but that they required even more intelligence and training to use the Weldon *properly* than to use the Watkin. That of course is easy to understand, although if you give the Weldon instrument to a man who has never seen it before, you can teach him in an hour or two how it is to be used. For instance, Officers have come to me, and I have soon taught them how to use the instrument, but they have not always seen that they would want months of practice with it in order to take ranges accurately. With the Watkin instrument they would not be able to take a range after, say, only half an hour's instruction, but with proper training the use of the Watkin instru-

1885. Class of 21 non-commissioned officers—					6 very good.
					12 good.
					3 failed.
" 16 " " "					3 very good.
					10 good.
					3 failed.
" 7 " " "					6 very good.
					1 good.

ment becomes mechanical, and it tells its own tale. Colonel Richardson says, "It rarely happens that a good natural distant direction point cannot be found on one side or the other." At the camp at Hay last year I attended the artillery practice that was carried out with range-finders, and I know that in *many positions* we could not possibly have found a good distant point. It is really very hard to find. With reference to the fourth method of working, mentioned by Colonel Richardson, I quite agree with Major Featherstonhaugh that you must not employ two observers. In all range-finding you have to observe *a point*. Now, if you see a body of infantry you may say, "Take *that Officer* as your point." Oh, yes, but *that Officer* is a different one in the estimate of No. 1 and No. 2, and the chances are that your second observer takes the wrong man. And then even taking to a man, say, a cavalry soldier, you must have an idea whether you are taking to his head or to his horse's nose. In this way, too, observers make terrible errors. We never allow a second observer with the Watkin instrument on this account, although we should save time immensely by doing so. Generally speaking, you have to take such objects as rifle-pits, shelter-trenches, and so on, often some little lump of ground which is very difficult to see, and which you cannot possibly explain to another man. I think, therefore, that the fourth method does not answer. With regard to length of base, there we come on to ordinary scientific ground. Apply it in any way you like, the human eye, unassisted by a telescope, cannot appreciate a difference of angle of less than about one *minute*. If you take a triangle and solve it, you will find that if you make an error of one minute in each base angle, whether you measure the exterior or interior angles, you make an error of something like 3 per cent. in the range, when the base is about one-fiftieth the sides, unless the errors happen to be in the right direction for correcting each other. You get very much less error in range as you get longer bases. Colonel Richardson has quoted the Aldershot trials to show that the Weldon range-finder is superior to the Watkin in accuracy. Now there were some inconclusive trials in 1883 when some damaged Watkin instruments were compared with some new Weldon range-finders, but even then the results reported do not appear to agree with Colonel Richardson's figures. I have in my hand my own report of the second trials at Aldershot in 1884 under my supervision. These are the results:—

	Error per cent. of range.	
	Weldon.	Watkin.
1,000 to 2,000	5·8	0·75
2,000 „ 3,500	4·97	1·00

The Weldon was rather better at the longer ranges compared to itself, but the error was nearly five times as much as with the Watkin. The errors, however, were not very great. The Weldon only made an error of 50 in 1,000 yards.¹

¹ In the trial referred to there were three observers, and about 400 observations were taken with two Weldon range-finders; they were used—

1. Without equipment; men as markers and the bases paced.
2. With pickets, but all bases paced.
3. With pickets and the bases measured.

One instrument read from 1 to 2 per cent. better than the other. The *best* gave the following figures:—

Mean Errors per Cent. of Range.

1st. Without equipment.		2nd. Pickets only.		3rd. Pickets and tape.	
1st and 2nd prisms.	3rd prism.	1st and 2nd prisms.	3rd prism.	1st and 2nd prisms.	3rd prism.
7·61	10·11	6·15	7·80	5·57	6·76

Major-General DRAYSON: I wish, Sir, to take up the history of this instrument a little earlier than I think Colonel Richardson has mentioned. In the year 1864 I had a great deal to do with range-finding, and the introduction of range-finding into the artillery. I found when I had non-commissioned officers to deal with, that the difficulty of their reading the vernier was so great that I used the Hadley sextant clamped at particular angles, so that they could not by any means alter the vernier; the angles I selected were $84^{\circ}17'$, which gives a range ten times the base, $87^{\circ}8'$ which gives 20 times, and $83^{\circ}33'$ the same as Colonel Weldon has used. After a time I thought it would be much more simple to get an instrument made by Messrs. Troughton and Sims, on exactly the same principle as a Weldon, with the exception that I used glasses instead of a prism. These glasses gave an angle of $87^{\circ}8'$, and a range twenty times the base. I was very much attracted by this instrument at first, and several old Officers of artillery, who had forgotten how to use the vernier, were delighted with it. As long as I was on Woolwich Common I could get my range admirably. There was a fine open space, and when we compared the distances with the Ordnance map, we found the results very accurate. But as soon as I got into the country, the difficulty mentioned by the last speaker occurred. I wanted a base one-thirtieth or one-twentieth of my range, and when I walked back to get it I got into a hedge, or a sand-pit, or something of that kind, and I could not get my range. I had to get the other man to move further off, and then he would say he could not get any further. The result was we gave up this system, in consequence of the base always necessarily being a certain proportion of that range; this, I think, is a defect in any range-finder. If you get a fine open level space where you can see distant objects, and see the second man, there is nothing better than the system I adopted. I am somewhat surprised to hear from Colonel Richardson that he seemed to think the first experiments made by Colonel Weldon were original. They are identically the same as mine made nearly twenty years before. Now I gave a lecture at the Indian United Service Institution, at Simla, in 1876, at which there were several distinguished Officers present, and amongst them Sir Frederick Roberts and Sir Peter Lumsden. Sir Peter Lumsden was so taken with the instrument that he suggested it should be supplied to the different garrison instructors in India. I told him I thought it would be no good, and that I did not recommend it. Some years after that Colonel Weldon produced his instrument, which is precisely similar to this, and I think it at least singular that he should claim it as his invention. I can answer one point raised by the first speaker, namely, that with this and a second instrument we can

The same ranges were taken with two Watkin range-finders, the average mean error per cent. of range being 1.03. That this is not an exceptional figure is proved by the results of the range-finding at Hay in 1895 by the range-takers of the batteries which practised there in succession, and which are marked in the columns as 1, 2, 3, &c.

	1.	2.	3.	4.	5.	6.	Remarks.
Number of observations	6	8	7	8	7	16	The range-taker of the seventh battery in camp was absent.
Greatest error in each series, per cent. of range ..	3.9	7.0	2.5	2.4	3.3	3.3	
Longest and shortest range taken	{ 1,906 800	{ 2,696 1,400	{ 4,050 1,605	{ 2,896 800	{ 2,896 610	{ 2,696 1,400	
Average error per cent. of range ..	1.5	2.9	1.0	0.96	1.4	1.7	

take ranges of moving objects as simply and exactly as we can objects not moving. It is not the case of one man holding the gun and the other pulling the trigger. One man stands with this instrument in his hand, and it is his business to keep the second man and the distant object in coincidence, and he does that by moving backwards and forwards; he keeps on doing it, and he has tremendous power of doing it, because if the base is only one-twentieth of the range, he need only move at one-twentieth of the speed of the distant object, so that he can actually keep a railway train in coincidence. The second man does the same thing, it is his business to move a little further off, or to come closer in; there is no difficulty whatever. I have taken steamers at Portsmouth and on the Thames, and at intervals of half-a-minute I have given what the range has been. One other point, I think, is very essential: it has been mentioned by Major White, namely, that you not only have to train your range-finders with the greatest care, but in addition to that you have to keep them in practice. Not long ago, when I was at Halifax, in Nova Scotia, we got some men who had first class certificates for having found ranges with the Watkin range-finder. The first thing that those non-commissioned officers said to me when I asked them to take a range was: "We have not used this instrument for two or three months; we are quite out of practice;" and they were so much out of practice that they could not get the range at all. I think the essential defect of any range-finder is where you have no mobility of angle and base, for if you are fixed to a particular base you will be running foul of objects just at the time you want to get your range, and so you may lose your opportunity and the time will be passed for the range being of any service at all.

Captain C. B. MAYNE, R.E.: I would like to say a few words, Sir, on behalf of the infantry, although I am myself an engineer. In the first place, the conditions of using range-finders for infantry and artillery are very different. The artillery often have to fight at very long distances, and in all cases want their range exactly, but under conditions which, in a large amount of cases, are different from those for infantry. It is a curious fact in infantry fire that when the men all fire with the same elevation, then from 500 yards and upwards, the mass of the bullets, or rather the best or inner 50 per cent. of them, fall fairly evenly over 100 yards; this fact should be borne in mind in constructing infantry range-finders, and it is upon this fact also that all the rules of firing on the Continent are based, especially with regard to judging distances by the eye. Abroad they say the average error of judging distances is one-eighth the estimated distance; but this may be under or over the range, so that the total error to be allowed for is one-fourth the estimated range. Up to 400 yards the total error of judging the range is under 100 yards (the length of the spread of the bullets), and consequently there is no necessity to use more than one elevation up to 400 yards, especially as the bullet remains under the height of a man up to that range if aim is taken as his feet. Up to 800 yards the total error to be allowed for of one-fourth is 200 yards, and therefore we must divide the men firing, and make one-half of them use a sight for 50 yards over, and the other half a sight for 50 yards under the estimated distance, so that their bullets will spread over 200 yards, and then cover the ground on which the objective stands, in that way. The same method can be used up to 1,200 yards, but there we must use three sights, one for the estimated range, one for 100 yards over it, and one for 100 yards under it, so as to cover 300 yards of ground with bullets. But that means a great expenditure of ammunition, and it seems that we can only really get the greatest efficacy for infantry firing that can be obtained by the use of a range-finder, which will give the range to within 50 yards up to 1,500 yards, the maximum range for infantry fire in the field.¹ Supposing we are in a defensive

¹ Perhaps this is a very severe condition, and a more just one would be to give the range within 100 yards up to 1,500 yards, and to within 50 yards up to 1,000 yards, which would require the use of one sight only up to 1,000 yards only, and two sights only up to 1,500 yards. This would suit the organization of our smaller units, as a use of three sights would find considerable difficulty in our ranks, unless we devote three whole companies for the purpose, because it is laid down in Germany that when three sights are used, a whole company (250 men) should be employed, and the German company is organized in 3 *züge*. When two sights are used they say

position, and the enemy has not arrived. Of course under such circumstances any range-finder can be used, and distances can even be measured if necessary. For the former purpose, I think one of the simplest range-finders is the plane-table. One advantage of this instrument is that with the same base one can find the range of any number of objects in different directions, whereas with all other range-finders, the Weldon, the Watkin, and so on, for each object (if they are not all in one line) one has to take a different direction of base, which is a very serious objection, especially when one is on a ridge, as would be the case for troops in a defensive position, because if the further end of your base lies over the ridge you cannot see the distant object to find its range. With the plane-table you can take a great number of ranges in any direction from the same base, and if it is done on a sufficiently large scale, and with a sufficiently large base, very accurate results can be got. But in action, when the "music" has begun, and we are acting on the offensive, I should like to see anybody trying to use any of these range-finders, having to move, as they would have to do, up and down the firing-line, in order to take a range in the midst of all the smoke which is hanging about both in front of the defensive line, observing the objective whose range is required, and in front of the attacking troops, making the light misty and dim. For such purposes, I think, that any range-finder for the infantry should not have a base longer than the length of a rifle, or of an Officer's sword. All the range-finders at present before the public are admirably adapted for the artillery, who are stationary and have ample time and everything else in their favour for using them, but for infantry who are moving, I think that any range-finder that requires a base longer than a rifle or a sword, as the case may be, or has an error greater than 50 yards up to say 1,000 yards as a minimum, is not of any value to infantry; I do not see how they are going to use it under fire. There are some range-finders that I have tried that allow of a small choice of direction in the base; one is a very small and handy range-finder called the Labbez, which allows about 5 degrees in choosing the direction of the base. I have also tried the "Bate" instrument, made by Messrs. Elliott Brothers, which is a new one, and can be attached to one's field-glasses, and also one latterly introduced by Mr. Steward, both of which allow of about 30 degrees choice in the direction of the base, and they all three employ the principle which Colonel Richardson pointed out, of measuring one exterior and one interior angle instead of two interior angles as is done by the Watkin. They all have given very fair results as compared with the Watkin. This choice of direction in the base line is one thing the Weldon does not give, nor does the Watkin.

Admiral DORS: Might I ask the cost of one of these Weldon instruments?

The CHAIRMAN: I don't think it is very much.

Colonel RICHARDSON: 1*l.* per prism; 3*l.* in all. In reply, I really seem to have very little to reply to, for most of the remarks have been made on other range-finders. Major Featherstonhaugh referred to the "Bolton." I can tell you that the Bolton range-finder was brought out after a lecture which I gave at Simla on the original Weldon instrument, and I heard from Mr. Bolton that it was nothing but the Weldon instrument over again.

Major FEATHERSTONHAUGH: I explained that; I said that they were practically the same thing.

Colonel RICHARDSON: Major Featherstonhaugh also said that the base was too long, and in particular that for mountain ranges it is too long. I have not had the opportunity of trying the new instrument on mountains, but it has a very much shorter base than the old one, which I tried a great deal in the Himalayas on the worst ground possible. I saw artillery practice carried on there with the aid of these range-finders with most excellent results. I am talking of the old Weldon range-finder. The mountain batteries adopted it, because it was the only range-finder that would find a range on such hills. With regard to moving objects the

that a whole *sug* or eighty men (that is to say about an English company) should fire to obtain a good result. Two sights could easily be used by us but not three sights, and any instrument which will enable us to make use of two sights only up to the extreme range of infantry fire should be eagerly sought after. Mr. Mallock's instrument seems to offer such an one.—C. B. M.

difficulty has been explained away by two other speakers, who have answered that question entirely, and in fact there is no difficulty whatever in finding the approximate distance of a moving object.

Major FEATHERSTONHAUGH: How do you know whether you are right?

Colonel RICHARDSON: We used to send a man out galloping. I had a signaller by me, and the mounted man was ordered to stop the instant a large flag or ball was raised. He was set galloping, and on the range-finders both saying "Right," which they did when each had the reflection of the man true on the other, the man was halted by the signal; he might perhaps move five or six yards after the signal was given, if he was trotting or walking, but when he was galloping, it was a little difficult to stop him, though he halted as soon as possible. The range was sometimes chained up to him, or it was sometimes taken using him as a standing object, or sometimes he planted a pole, so as to mark the spot still more accurately. The errors were found to depend more on the training of the men who had to find the range than on anything else. The ranges were found to be exceedingly good with well-trained men, and we usually found that a man was well trained after he had been at work about a fortnight. Major White, who is an instructor in range-finding, says that months of practice are required, but that is not my experience. I also have been an instructor, have had a good deal of practice with this particular range-finder, and I have not found it so at all with a good system of training. Major Featherstonhaugh also mentioned that astronomical observations can be very accurately taken; no doubt they can, but then think of the time they take! If you go into minutiae you can take ranges with extreme accuracy; you take your theodolite, and you measure bases and so on, but what I look for is speed.

Major FEATHERSTONHAUGH: I said that the mean error was no guide to what the extreme error might be.

Colonel RICHARDSON: I do not know that; that is a mathematical question I will not go into. I think the mean of many observations gives a very fair idea. It appears that Major White's idea is that a range must be found from an exact point. To me a yard or two one side or other of a fixed point makes very little difference, because I can add two or three yards to the range found without difficulty. Although I have taken many thousands, perhaps hundreds of thousands, of ranges, I have never found these difficulties about the base, though no doubt difficulties may be found if sought for. There is certainly no difficulty in getting the objects practically in the true plane. The eye alone tells you that. Look at the number of ranges which have been found, and are constantly found, with this instrument with a close approach to accuracy. I do not think there can be any great inaccuracy in it from this cause. There is occasionally, but very rarely, a difficulty in finding a distant point, and then the simplest way is to send out a man, which is done extremely quickly, and you get very fairly accurate range results. I have not found that two observers always fall into error. My experience is you can train men to work perfectly well together. Major White claimed to know the working of the Weldon instrument very well, but talked of the instrument measuring the angles at the base with a base of only 1 in 50. I tried to explain that the base for observing purposes in the Weldon is the far-off point, and not the base of 1 in 50. I particularly tried to point that out, and I am sorry that I did not make myself well understood.

The CHAIRMAN: We have another paper before us, and as the time is passing rapidly, I will only make one or two observations on Colonel Richardson's paper. It so happens that when I was in Calcutta I had the opportunity of trying both range-finders, the Watkin and the Weldon. I greatly admired the Watkin range-finder, and thought it a marvellously ingenious instrument, but much too delicate for rough usage. I certainly did think that the Watkin range-finder in the hands of the British soldier would be likely to be soon damaged irretrievably; but Major White says he has great experience of it, and found it answer very well. As regards the Weldon range-finder, it so happened that the chief assistant of my mathematical instrument office in Calcutta, Mr. Bolton, constructed what he called the Bolton range-finder, which was the same in principle as the Weldon and made with similar glass prisms, but with angles which, I think, were a little different.

He also constructed an ingenious stand for holding the instrument, and claimed that with the assistance of this stand he could get very much more accurate results than could be got by holding the instrument by hand. In certain instances his distances were checked by triangles measured with 8 and 10-inch theodolites, with great accuracy by practised surveyors, and they came out remarkably well. But I pointed out to him at the time that he could not expect to always have a great plain, as the *maidan* of Calcutta, to carry on observations of this kind; if he went up any of the adjoining streets, and wanted to know the distance of an object 400 or 500 yards off, he could not measure it; he could not have a sufficient base for the measurement, the breadth of the streets being inadequate. It struck me, therefore, there was an objection to the Weldon range-finder, in that it necessitated a compulsory length of base, one-fortieth or one-fiftieth of the distance of the object measured. I think we must all be very much obliged to Colonel Richardson for bringing the matter forward, for it is desirable that our Officers should know as much as possible of all the range-finding instruments which have been invented. I feel sure then that you will all join with me in giving a cordial vote of thanks to Colonel Richardson for his interesting paper. I have now to introduce Mr. A. Mallock, who has another instrument to describe to you, one of a very different kind, for it enables ranges to be found by measurement from short bases instead of long ones.

NOTE ON A SHORT BASE RANGE-FINDER.

By A. MALLOCK, Esq.

By the kindness of the Council of the Royal United Service Institution I am allowed to bring to your notice a range-finder having a base not more than 5 feet long, which is intended to give ranges up to 2,500 or 3,000 yards, with an error of, perhaps, a little more than 100 yards at the latter distance.

For the purpose of more easily comparing the actual performance of the instrument with its theoretical capabilities, I will, before describing its construction, consider one or two questions connected with distance measuring in general. Although these questions are doubtless familiar to all present, they will serve to bring into view the limits of accuracy attainable with short base instruments. The first principles involved, which are common to all distance measurements, will thus be separated from the mechanical and optical details of the particular instrument before you.

Measurements of distance depend in general on the knowledge of the angles of a triangle and the length of one of its sides, but when, as in range-finding, the angle opposite the base is very acute and the triangle is either nearly isosceles or right angled, the values of the acute angle and short side are all that are required for a very approximate measure of the length of the remaining side.

Dealing only with such acute angled triangles, I will inquire what error is produced in the result by a given error in the measurement of the acute angle. In the triangle ABC, of which C is the acute angle, let p be the ratio of AC to AB, and $\angle CAC = \epsilon C$ the error in the measurement of C, then KC, the error in the measurement of AC due to the error ϵC , is $\frac{AC}{AB} \epsilon C \times \frac{AC}{AB}$ or $p^2 \epsilon C$, taking the length of AB as unity;