A COURSE

OF

MILITARY SURVEYING;

INCLUDING

SKETCHING IN THE FIELD,

PLAN-DRAWING, LEVELLING,

MILITARY RECONNOISSANCE,

&c. &c. &c.

ALSO A PARTICULAR DESCRIPTION OF THE

SURVEYING INSTRUMENTS,

COMMONLY EMPLOYED BY MILITARY MEN, WITH INSTRUCTIONS FOR USING AND ADJUSTING THEM;

PLATES AND DIAGRAMS.

BY MAJOR BASIL JACKSON,

LATE OF THE ROYAL STAFF CORPS.

SECOND EDITION.

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THIS BOOK HAVING BEEN ADOPTED AT THE HON. EAST INDIA COMPANY'S MILITARY COLLEGE,

BY ORDER OF THE COURT OF DIRECTORS,

IN CONSEQUENCE OF

THE RECOMMENDATION OF COLONEL PASLEY, C.B., OF THE ROYAL ENGINEERS, PUBLIC EXAMINER AND INSPECTOR OF THAT INSTITUTION,

THE AUTHOR TAKES THIS OCCASION TO ACKNOWLEDGE THE HONOUR THEREBY CONFERRED UPON IT.

NOTICE TO THE SECOND EDITION.

SOME very satisfactory Testimonials of the utility of this Work have reached its Author since the publication of the first edition; many individuals having made great progress in Military Surveying without other assistance.

The new Edition* contains much additional matter, and the Work having undergone a careful revision, the Author submits it with confidence to the military profession.

* The Author considers it but due to Messrs. PALMER and CLAYTON, to say, that the printing of this volume has been done much to his satisfaction.

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PREFACE.

Having served more than twenty years in the Royal Staff Corps,* after going through a course of education at the Military College, I venture to recommend the principles and practice of surveying and sketching that I have found most convenient and useful.

The design of the following work is to pioneer the way, and enable young officers and students for the Military profession, to acquire a competent knowledge of the readiest methods of making maps and plans, taking topographical sketches, &c. &c., unaided by an instructor: with this object, the plainest rules and examples are given, in order that no part of the Treatise should be found too difficult for a beginner of ordinary diligence and ability to understand and follow.

* A war corps, organized and armed as a body of infantry, but trained to the duties of Field-engineering. The officers were mounted, and expected to perform the services of the Quarter-Master-General's Department — the Field-officers ranking as Assistants, and the Captains and Subalterns as Duputy-Assistants; receiving, when in the field, forage and other allowances according to their staff-rank. The qualification for an officer was a military education, and four-fifths of the soldiers were mechanics. This corps was not broken up until many years after the termination of the late war, its services having been made available in the colonies.

My own experience has served to convince me, that our system of military education is not sufficiently practical; and, acting on this opinion, instead of trying the student's patience and perplexing him with theory, I send him at once to the field. It is desirable, however, that, as far as possible, practice and theory should proceed by equal steps.

In justice to the Authors of other works on Surveying, both civil and military, I shall mention such publications as I have consulted during the preparation of the following pages. These are:—Adams's Essays; Outlines of a System of Surveying, &c., by Major Sir T. L. Mitchell; A Treatise on Practical Surveying and Topographical Plan-drawing, by G. D. Burr, Esq., Professor of Military Surveying at the Royal Military College; Treatises on Mathematical Instruments and the Principles and Practice of Levelling, &c., by F. W. Simms, Esq., Surveyor and Civil Engineer; Professional Papers, Royal Engineers; Outline of the Method of conducting a Trigonometrical Survey, &c., by Captain Frome, Royal Engineers; French Aide-Mémoire, &c. An excellent Plan and Report of the Route between Malaga and Granada will be found under the head of Military Reconnoissance, for which I am indebted to my old friend and brother officer, Major C. Rochfort Scott, which I have inserted as models worthy of imitation.

INTRODUCTION.

Frederick, of Prussia, originated what may be termed, Military Topography, or the art of depicting the face of a country on a large scale in aid of military operations. In his day, the countries of Europe were very imperfectly mapped: we now, however, possess tolerably correct maps of most of the European States.

But general maps, although indispensable in warfare, are never on a scale extended enough for every purpose. The Trigonometrical Survey of England, for instance, on a scale of an inch to a mile, is quite sufficient for combining military movements generally; but a Commander in the field requires also to have more detailed plans of the territory over which his operations are likely to carry him, for the purposes of manœuvring and disposing his forces to the greatest advantage, both for attack and defence.

A perfect knowledge of the ground is, in short, necessary for a General. To obtain this knowledge by a personal examination amid the many calls upon his time and attention, occasioned by the varied and important duties he has to perform, is manifestly impossible; besides, he must not only examine, but also retain in memory the result of his inspections. Hence arises the necessity of having attached to the Staff of an army, certain individuals qualified to furnish plans, sketches, and reports of a country. Such were in our service, during the late war, the Officers of the Royal Staff Corps.

It may here be observed, that a good plan conveys to the mind a more perfect image than can be obtained by looking at the ground itself. This may appear paradoxical, but it is, nevertheless, true. A plan enables us to examine and compare the great features of a country: we trace on it the directions of lines of coast, of mountains, rivers, roads, forests, &c.—distance is nothing: we see the country, twenty, fifty, a hundred miles off: we can estimate the comparative heights of hills without having to bear in mind that the angle subtended by a mountain varies with its distance from the eye; or that such an art as perspective exists. Nay more, it may be asserted, that a really good plan is fully equal, I had almost said superior, for military purposes, to the best model.

Further, the utility of military plans is not confined to the period of actual operations in the field; their benefit is often equally felt afterwards. Without them, what would be the science of war? The profound combinations of the General, as well as the graphic descriptions of the Historian, would indeed avail us little, if the narrations of the latter were not illustrated by plans.

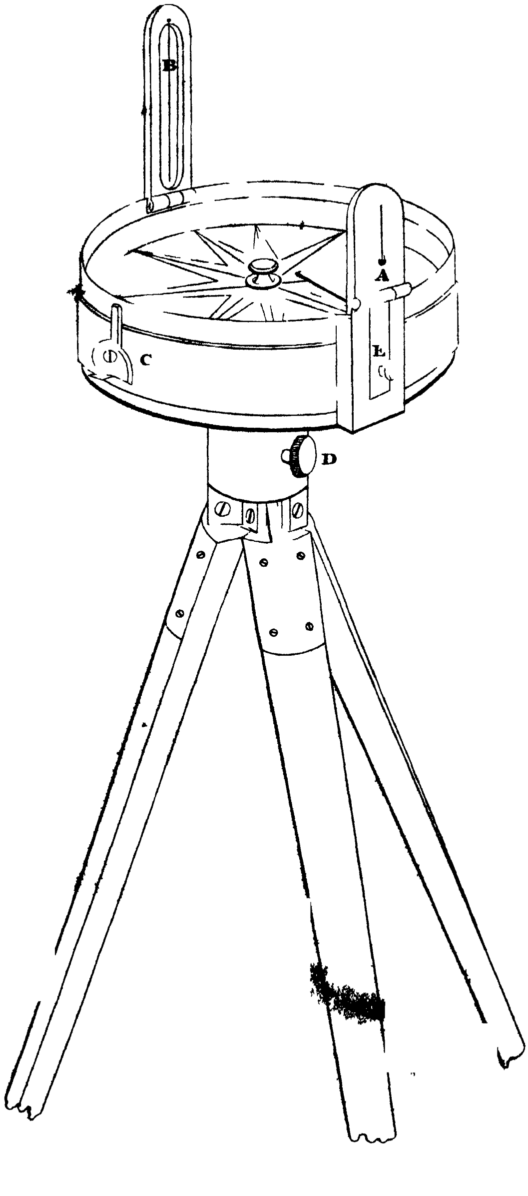
A few remarks upon Plans may not be amiss in this place: —

In Plans, there are three things to be desired:— the first, is correctness to a certain degree, without which a plan is worse than useless; the second, is clearness, in order that every part may be understood; the third, is beauty of execution, which is generally found to accompany the second of these desiderata. The last, however, being the only point upon which the majority of persons are capable, or rather fancy themselves so, of giving an opinion, naturally excites their chief attention.

When examining a plan, how rarely do we think of the labour with which it has been produced: the triangulation to establish certain points, as landmarks: the arduous business of surveying every yard of road and stream: the ability and care necessary when sketching the forms of the ground, and the minute attention required for innumerable minor details: how seldom do all, or any of these considerations, enter into our thoughts when a plan is shown to us. And yet the merit which attaches to the mere drawing, — the language, as it may be termed, of the surveyor — an accomplishment, little more than mechanical, is trifling indeed, when compared with the amount of talent and labour employed in the formation of a good plan. Perhaps *time* may afford some criterion whereby to judge of the comparative value of plan-drawing and plan-making. An expert draftsman will in the space of two or three days produce a copy of a plan, the field-labour and plotting of which may have employed him for a whole year.

In conclusion: The service requires not merely that plans should be executed, but also, that the General and others, for whose information they may be prepared, should understand them. Hence, *every officer*—for all hope to rise in rank—ought *to be sufficiently acquainted with Military Surveying to understand its language as used in a plan, or—to employ an erroneous, but common mode of expressing, the same thing*—should have a knowledge of the principles of plan-drawing.

Certain details in a plan, as roads, rivers, houses, woods, &c., are at a glance, comprehended by every one; but to distinguish the features of hills, mark their connexion, judge of their comparative height, steepness of slope, and other points relative to ground; which are the most important considerations in a purely military plan, requires a real knowledge of the art. And it may further be observed, that few officers who have not had the advantage of a military education, can ever understand ground as exhibited in a plan.



THE SURVEYING COMPASS.

MILITARY SURVEYING,

ON SURVEYING AND SKETCHING WITH THE PRISMATIC COMPASS.*

SECTION I.

PRELIMINARY OBSERVATIONS. — PRISMATIC COMPASS. — TAKING BEARINGS — INSTRUMENTS AND IMPLEMENTS REQUIRED.

TRIGONOMETRICAL SURVEYS AND MILITARY SKETCHES of any consequence, are guided by the same principles; triangulation is the basis of both. In *sketches*, however, we do not look for the same degree of accuracy that is imperative as regards a *survey*. The latter is an operation demanding considerable time, and requires that superior instruments be used.

It has been the practice to consider a knowledge of regular surveying with the theodolite as a necessary foundation for military sketching; but I venture

* A slight acquaintance with the elements of Geometry is necessary to enable a student to comprehend the subject fully. A knowledge of Trigonometry is not absolutely required in this kind of surveying.

to think that much benefit would arise from reversing this system; and am glad to find my own views in accordance with those of the chief draftsman of the ordnance department: Mr. Howlett says, "The method of surveying by the prismatic compass appears to be so valuable for military purposes, and the process so well adapted to teach the principles of surveying, that it might perhaps be found worth consideration, whether it should not be perfectly understood, before a theodolite be put into the hands of a pupil."

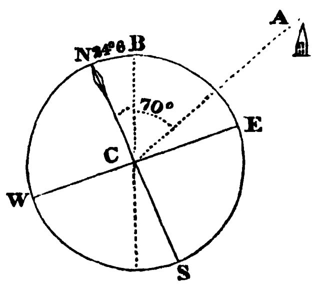
The prismatic surveying compass, known as Schmalcalder's, when mounted on a stand, and having the card divided to 20′, that is, each degree into three parts, enables the observer to obtain a bearing to within three or four minutes of a degree, by estimation.* When held in the hand, a bearing may be depended on to about fifteen minutes, provided the wind is not so violent as to shake the hand of the observer. It is usual to watch the vibration of the divisions on each side of the vertical hair, and take the mean. I have found it most convenient when the card is divided into twice 180 degrees, instead of having it numbered from 0 to 360 degrees. The stand is better without levelling screws; they are troublesome, and, I may say,

* Messrs. Troughton and Simms, 136, Fleet Street, have lately divided the cards of their smallest prismatic compasses to twenty minutes instead of to half a degree, as formerly, which I consider to be a great improvement.

almost useless; for the card is easily made level enough to play freely, by shifting the legs of the stand: these should be between five and six feet long, for the convenience of the observer, and that the instrument may be above the height of brushwood, &c., which often impedes the view.

I shall not here enter into a description of this well-known little instrument, which, however, will be found further on: a quarter of an hour at any optician's will suffice to make any one acquainted with its use.

In surveying with the compass, the bearings of objects are taken from the *magnetic meridian*. Let NS represent the magnetic needle or meridian, W the west, and E the east; and suppose the sights of the compass are directed to the spire A; then if the angle NCA be 70°, for example, the spire is said to bear 70° north-east, or 70° from the magnetic north towards the east.



The *variation* of the needle is its deviation from the true north. In this figure, the angle NCB represents the variation, BC being considered as the true meridian. The variation is now about 24° west, at London.

Having made himself master of the instrument, so as to be able to take bearings, I recommend the student to attempt the survey of a road; the mode of doing which I shall endeavour to render very easy to him. He will require to be provided with a sketching case, about ten or eleven inches square, an ivory rectangular protractor, such as every case of mathematical instruments is furnished with, and a black-lead pencil. His paper, asses-skin, or what is preferable to either, a piece of paste-board, fits into the sketching case, and must be ruled all over with very fine lines, exactly *parallel* to each other, and at *unequal* distances, varying from a quarter to three-eighths of an inch apart.* The purpose to be answered by ruling the lines at unequal distances, we shall presently see. The protractor is six inches long, and an inch and three-quarters wide, having *across it* a number of very fine lines at right angles with its length, and at *equal* distances from each other. These lines are regulated so as to form a scale of four inches to a mile, but may likewise be used for paces or yards.

The student is now prepared to begin upon the road.

* *Sketching blocks* have lately been used at Addiscombe College, for sketching and plotting in the field, and found very convenient Each sheet of paper composing the blocks has the parallel lines printed on it from a steel plate, which not only ensures the accuracy of their parallelism, but gives the lines very fine, which is a desideratum. A useful size for a *block* is twelve by ten inches, and it fits into a patent leather case, which may be slung over the shoulder or attached to a saddle. They are made by Messrs. Reeves, 150, Cheapside.

SECTION II.

METHOD OF SURVEYING A ROAD BY THE COMPASS, AND PROTRACTING IN THE FIELD.

THE compass is set up at the point from which we purpose to start, as A (plate II., fig. 1); and care being taken that the card be level, so as to play freely, a mark is placed at B, where the road turns to the right; the sights of the instrument are then directed to the mark at B, and we find, when the card has settled, that the vertical hair cuts the 29th degree; the bearing of B is therefore 29° north-east —the mark at B lying towards the east point from the magnetic north.—I would observe, that in ordinary road sketching, it is not usual to set up any marks: some object will present itself, which must be kept strictly in line when pacing the distance; thus, much time is saved.

Next, to protract, or lay down the bearing of B upon our paper, which has upon it the parallel lines at *unequal* distances, to be considered as *east* and *west*, and therefore not meridian lines, which are north and south.

The protractor has across it, as we have already noticed, a number of lines. Now, fix on any convenient part of the paper, make a dot, and surround it with a small circle, thus ⊙, which denotes a station. Place the centre of the protractor at this point, and endeavour to make any one of the lines which are drawn across it, to coincide with one of those upon the paper, being careful to keep its centre very exactly on the point. This being effected, the protractor is adjusted, that is, lengthwise *it will lie north and south*, while its ends will, of course, be east and west. Make a small mark on the paper at the 29th division or degree, when the protractor may be removed. A line is then drawn from A, through that mark, which line will bear 29° N.E. You now measure the distance from A to B, which is effected by pacing, using the regular marching step of thirty inches. To lay off the distance measured: upon the line on your sketch, apply the edge of the protractor, which has a scale marked on it, or use a slip of paper upon which a scale of any size you please has been prepared, and mark off the distance. Finally, trace lines, as shown in the figure, to represent the sides of the road, and the first station is completed.

A mark is next placed at C, and its bearing taken from B, namely, 59° N.E.

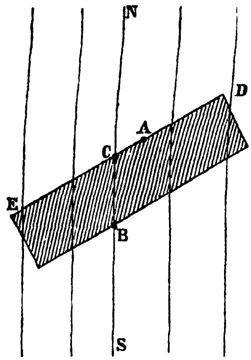
When we come to take the bearing of D from C, we find the sights of the instrument turned to the left of the magnetic north, while the vertical hair cuts the card at the 156th degree. Now, in the common mode of reading a bearing, we should say that D bore 24° N.W.; but our compass card reads, from north round to south, 180°; and then, from south round to north, 180°, to complete the circle of 360°. Consequently, all bearings lying on the *west* side of the meridian, are read off from south towards the north; and therefore in the present instance, the bearing of D is 156° N.W.: that is, 156° from the south pole of the needle, round towards the north pole; and as this falls between the W. and N., it is styled north-west.

The expression of bearings may, however, be simplified, if we distinguish them only as *east* and *west;* we shall, therefore, cease to designate them as being so many degrees north-east, south-west, &c., and term all bearings taken from the north pole of the needle, up to 180°, as *east;* while such as are measured from its south pole will be *west.*

Fig. 2, plate II. represents the paper as prepared with parallel lines. The protractor is adjusted to station A, for laying down a bearing from north to east, and on to south. At ⊙ C, it is likewise adjusted, but reversed in its position, for the purpose of laying off the bearing of D, which, from what has just been observed, must necessarily be reckoned from south, round towards north, passing by west, the situation of which is indicated by 90° on the protractor, the west point being at right angles, or 90° from south.

When a protractor is not furnished with cross lines for its adjustment, by the east and west lines drawn on the paper, these may be considered as meridians (north and south); by means of which, bearings are laid down in the following manner:—

Suppose that we want to protract a bearing of 60° E. from a point A. Place the centre, C, of the protractor on any meridian, N S, and turn it as on a pivot, until the 60th degree, reckoning from E, coincides with the same meridian at B. The protractor is then moved up or down, being careful to preserve its position on the meridian, until the upper edge touches the point A, when a line drawn from C through A will make the angle NCD = 60° = ECB.



It may be as well to mention here, that when surveying a road, or river, &c., with the compass, bearings need only be taken at every *second* station; as will be seen when we come to speak of surveying with a theodolite and by the needle. To explain this now would only embarrass a beginner.

The student will do well to make himself master of the two first sections, before he proceeds further: with a little attention, I can assure him that the subject, thus far, will occasion him no embarrassment whatever. It is, perhaps, superflous for me to mention that I consider it as entirely new to him, and have written accordingly.

SECTION III.

OF THE SIMPLEST METHOD OF SKETCHING A PORTION OF GROUND;* A MILITARY POSITION, FOR INSTANCE; WITH THE AID OF THE COMPASS.

THE paper must be ruled with parallel lines at unequal distances, as before.

Previously to commencing the sketch, it is best to go over the ground and examine it, so as to fix a plan of it on the mind. Then select a few prominent points for stations, from which bearings are to be taken to all conspicuous objects contained within the limits assigned to the sketch; such as houses, remarkable trees, a windmill, church steeple, &c. Next, select the longest and most level space on which to measure a base, which may be either on the summit of the ground you are to sketch, or along the bottom, as most convenient.

Plate III. represents a hill, partly surrounded by a road, of which our object is to take a military sketch with some degree of accuracy. On inspection, it is found that the direction A B is most favourable for the base line. E, D, and C, are

* The term *ground* is generally to be understood as applied in contradistinction to a flat or level; so, whenever it is met with in the course of this work, hills or elevation will be meant.

situations eligible for stations. Now, the compass being placed at A, the bearing of E is taken, namely, 61° E. D is found to bear 106° 30′ E. B, 172° 20′ E. C, 24° 30′ W. Protract these several bearings, by marking a point, A, on the paper, in such a situation as will admit of the whole contemplated sketch being contained on the sheet, and adjusting the ivory protractor to the lines, as on the former occasion, which will then lie in the position that is shown in the figure. Measure the base A B. The mean of three times pacing it over, gives, suppose, 1130 paces, of 30 inches each. Lay your scale along the line which indicates the bearing of B, and mark off the number of paces, which fixes the point B.

Again, plant the compass at B, and take the bearing of C, 124° W.; of A, 172° 20′ W.; of E, 11° E.; of D, 22° 30′ E. It will be remarked that the bearing of B from A, and that of A from B, give the same number of degrees and minutes: they form, in fact, alternate angles with their respective meridians, and present, when laid down, the same straight line; furnishing a proof that the bearing taken at A was correct.

The several bearings taken from B are now to be protracted, and where the lines intersect or cut those drawn from A, fixes the points C, E, and D.

The observer should now look around, and notice what objects are visible, that it may be advantageous to fix, with a view to assist him in sketching, and filling in his work. For this purpose a bearing must be taken to the farm house; also to the point G, where a road turns off. The farm bears 89° E., and G, 50° 30′ W. These two bearings are then to be protracted. Proceed with the compass to C, and take the bearing of G from thence, 6° W., which, on being laid down, cuts the bearing taken from B, and determines G. While at C, it is perceived that the point F, where a road branches off, must be fixed: a bearing is therefore taken to F, namely 175° 30′ W. The compass is then carried to D, and the position of the farm house is decided by a bearing that cuts the one taken from B.

It is a maxim in surveying, that when fixing any points of importance, both acute and obtuse intersections are to be avoided as much as possible. The nearer an intersection approaches to a right angle, the better: hence, in selecting primary stations, we should endeavour to have them so placed, that bearings which determine them shall intersect or cut each other as near at a right angle as circumstances will permit.

This observation applies particularly to the kind of rough surveying now under consideration; for it is manifest that some degree of error must attend every operation performed; for instance, the base line is measured by pacing—our compass only gives a bearing to within three or four minutes of the truth—the protractor is even more inaccurate, and, with every care, some error will attend its adjustment to the parallel lines. Now, if to all these unavoidable sources of error, we add such as will attend a very acute intersection, primary stations so determined, from which other points in the sketch are afterwards to be derived, must lead to great incorrectness.*

Referring to the sketch before us, E standing on an elevated knoll, is higher than any other of the stations; and supposing the sketch extended beyond the limits here assigned to it, the point E, from its superior elevation, which enables us to look well around, ought to be carefully fixed. In this view, the lines A E and B E intersect too acutely for the degree of accuracy that is desirable, and ought therefore not to be solely trusted to; especially as station D furnishes an opportunity to correct the position of E. When at D, therefore, the bearing of E is to be taken for this object.

Lastly, the bearing of F is observed from E, and the line C F is intersected, thus fixing F where the roads meet.

The contours of the hill should be sketched in during the foregoing operations. Thus, after protracting the bearings taken at A, the declivities

* The student is not to be alarmed at this array of causes productive of error. In a sketch comprehending an area of a square mile, the most distant points will not be generally more than 30 or 40 paces out—a matter of little moment in a military sketch. But it was necessary to warn him on the subject.

near that station are sketched in, having reference to the lines laid down. In the direction of C, for instance, we find that at 140 paces a descent begins, and at 145 paces further we regain the summit—still walking direct upon C. When C is fixed, a curve is swept round to meet what was sketched from A; and thus the business proceeds. But I shall not dwell longer on the *sketching* part in this place—proposing, in a subsequent section, to try and render the process intelligible to the student.

With regard to the road in our sketch, we find three points on it laid down, namely, F, G, and the farm house: the intermediate portions of it are either sketched in by the eye alone, or bearings may be taken along it, in the manner we have already seen (Section II.) to close from point to point—as from F, closing on G, and from G, on the farm.

If it were wished to carry the sketch over a greater extent of country, bearings to distant objects could be taken from points already fixed, as E, F, G, &c., and their several situations determined; and thus a net-work of triangles might be formed, similar to those of a trigonometrical survey. Indeed, our sketch is a minor description of trigonometrical survey. There is the base line AB. The primary stations, A, E, D, B, and C, with triangles formed by their bearings, laid down from each end of the base. Nothing can be more simple and easy than such an operation; and, notwithstanding the numerous sources of error, above stated, a few square miles of country may be laid down in this manner with sufficient accuracy for every military purpose.

A scale should accompany each sketch, and a meridian line must be laid down.

SECTION IV.

OF FINDING YOUR PLACE IN A SURVEY OR SKETCH WHEN FILLING IN.—GENERAL OBSERVATIONS ON MILITARY SKETCHING.

It is advisable in all kinds of surveying to have few original stations, and these as wide of each other as the nature of the country will allow. The primary points being accurately determined, such intermediate stations as become necessary when filling in, are readily obtained in a very simple manner, by taking the bearings of two stations previously fixed; which has been called finding your station by *interpolation*, and is a truly useful little problem, that I shall now endeavour to explain. I may mention that there is another method of finding your place on a map or plan, by observing the two *angles* formed between *three* fixed points, which will be noticed at a more proper time.

With respect to the division of the compass card, it will be remembered that I recommend its being divided into twice 180°, instead of carrying the numbers round from 0 to 360°; the advantage of which will be again seen here.

Let the circle N E S W (plate IV., fig. 1) represent the compass, having a line, H L, passing through its centre: the circle being divided into twice 180°, that is, the semicircle N E S is numbered from 0 to 180°, beginning at N; and the other semicircle S W N is numbered in like manner from S. Now, according to this mode of dividing the compass card, the bearing of the object H from C is 130° W., while that of the object L, from the same point C, is 130° E. H C L being a straight line — or it may be expressed thus, N S and H L being two right lines, cutting each other at C, the opposite angles are equal, namely, the angle H C S is equal to the angle N C L.

Again, let PH and BL be parallel to the meridian NS; these lines then become the meridians of the objects H and L respectively;* and PH being parallel to BL, the alternate angles PHC and BLC are equal. Hence, if the bearing of the object H taken at L be 130° W., the bearing of L taken at H will be 130° E.

For the application of the above to our immediate purpose, namely, to find the place of a third station, by means of two stations already laid down on the paper:—

Let A and B (plate IV., fig. 2) be two stations, whose places are fixed, and we want to determine the point C. Take the bearing of A, 128° W.: having done which, we know, from the foregoing explanation, that C bears from A, 128° E. Adjust the protractor at A, by means of the east and west

* Strictly speaking, meridians are not parallels, but they may be considered as such for surveying purposes.

parallel lines, and lay off 128° E., the bearing of C; which point C must, we know, lie somewhere in the line thus obtained. Next, take the bearing of B, 63° E., and having adjusted the protractor at B, lay off 63° W. and where a line drawn from B (to represent this bearing) cuts the line or bearing drawn from A, is the required station C.

The above may be put into a short rule: thus—To find your station by observations taken to two points already known, protract *from those points* the *opposite* bearings to what you observe, and their intersection fixes the place sought. For example, if the bearing to a point be 20° E., protract from that point 20° W., &c.

Observe, that the nearer your two bearings meet at a right angle, the more correct will the station be determined: and also, that when a third fixed point can be seen, a bearing to it will serve to corroborate your other observations; and a point so obtained, namely, by the exact meeting of three bearings, becomes as good as any other point.

The above is a very useful problem — indeed, indispensable when sketching ground and filling in a survey.

GENERAL OBSERVATIONS ON MILITARY SKETCHING.

The Quarter-Master-General, or other person directing the preparation of military sketches on active service, will usually determine in what manner they are to be performed. For instance, should the theatre of war lie in such countries as Germany, Belgium, France, Italy, &c., of which portions, if not the whole of their respective territories, have been carefully surveyed, and good maps published; directions may, perhaps, be given for the principal points to be laid down on an enlarged scale from such maps, and then for the features of the ground, and every requisite detail, to be filled in with reference to those fixed points.

This mode was adopted by Sir George Murray, when Quarter-Master-General to the British Army of occupation in France, under the Duke of Wellington, during the years 1816, 1817, and 1818. And in this way all the territory over which the cantonments of our army extended, was carefully sketched by the officers of the Royal Staff Corps.

That such a method was pursued by so distinguished and experienced an officer as Sir George Murray, and sanctioned by the Duke, is sufficient to recommend its adoption whenever very *extensive* sketching is wanted, and that a correct general map is at hand.

In default of good maps, recourse must be had to triangulation, as was always practised under the same authorities in Spain, when the method of proceeding does not differ in principle from a regular trigonometrical survey. But the slow methodical course of a regular survey is unsuited to the occasion, neither is the utmost degree of accuracy necessary for general military purposes. I would, however, recommend that the base line be obtained with all the care possible, as upon it depends the correctness of all subsequent operations; and, also, that the principal stations be determined by means of the theodolite.* After which, the filling in may be rapidly done with the compass alone.

A few individuals, expert in the performance of such duty, may, in this manner, cover a large extent of country in a surprisingly short space of time.

The object of delineating the face of a country has been already stated: namely—to enable a commander to manœuvre and dispose his force to the greatest advantage, according to the nature of the ground on which he is operating.

Although it is a good maxim to entertain, that plans for his information ought always to be as exact as possible; still, supposing the nature of the ground to be correctly shown, and its most

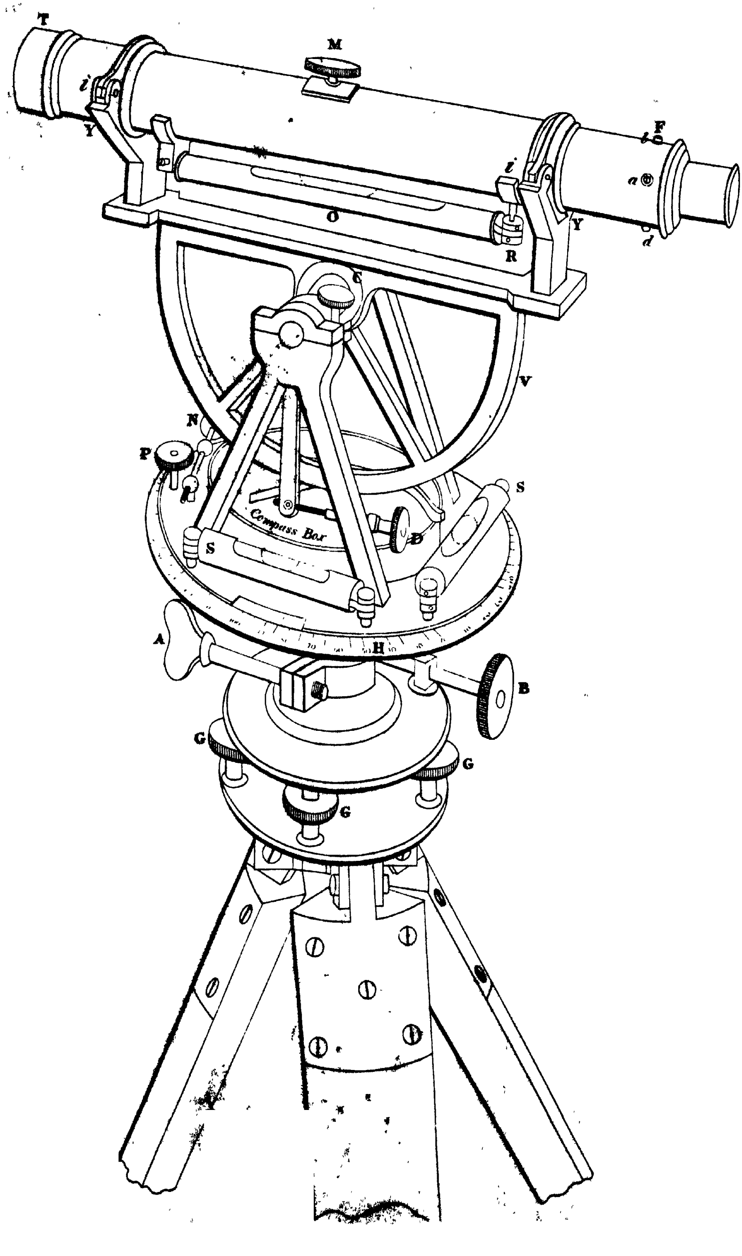
* If no theodolite can be obtained for this purpose, and provided the proper stations do not lie greatly above or below the horizontal line, a sextant will determine the points more accurately than the compass.—See further on, under the head of Pocket Sextant.

important features given with tolerable accuracy, it does not seem that a laborious attention to minor details can ever be of sufficient consequence to justify the employment of the time they necessarily occupy.

Let an officer beware, however, lest any errors in his plans should be of a nature to lead a General astray. It may be of little moment that a road is represented in a sketch fifty or a hundred paces longer or shorter than the truth; but if a range of elevated ground, near which a road passes, be shown as out of cannon shot from such road, when it is in reality within range, the blunder may be attended with serious consequences.

In active warfare, rapidity of execution in sketching is, perhaps, of more avail than great precision; and an able officer must judge for himself what degree of exactness the time allowed him will admit of, as also what portion of his task requires most attention. And such an individual need not be told that in the delineation of particular military positions, great care and attention must at all times be bestowed.

PLATE V.



ON SURVEYING WITH THE THEODOLITE.

SECTION V.

A DESCRIPTION OF THE THEODOLITE.—ITS ADJUSTMENT IN THE FIELD.—TAKING ANGLES.—VERNIER SCALE.

THE student who has carefully considered what is contained in the preceding sections, must have acquired some knowledge of surveying. It has already been observed that the principles of the art are the same, whatever may be the extent of work to be performed, or the kind of instrument used. This he will find to be the case as we proceed.

The Theodolite (plate V.) is the most perfect instrument used in surveying, as it gives the horizontal angles without reduction.* It is composed of a telescope, TF; with a spirit level, O, attached. A vertical arc, V, for measuring angles of elevation and depression. A plate, termed the horizontal circle, H, having upon it cross spirit levels, S,S. A compass. Parallel plates, with four vertical

* An explanation of the difference between angles taken with a theodolite or compass, and those measured with a sextant, or other reflecting instrument, will be found in treating of the pocket sextant.

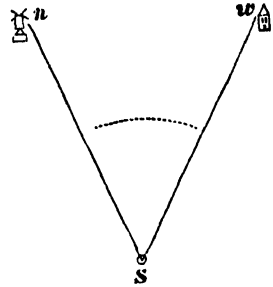
screws, G, for levelling the horizontal circle. A clamping screw, A, to prevent the horizontal circle from moving round. A tangent or micrometer screw, B, to turn the instrument slightly, after being clamped by the screw A. A screw, P, for fixing the upper or index plate to the horizontal circle, H, which may then be slightly turned for a nice adjustment of the telescope to an object, by means of the micrometer screw, N. The instrument is mounted on three stout legs.

When in perfect adjustment, the horizontal circle *is truly level. The vertical arc is in a plane, perpendicular to the horizon. The line of sight, or of* collimation *(i. e.,* axis of *the* telescope), must be true, and the level attached to *the* telescope must be parallel to the line of collimation.

The theodolite is set up thus:—Place it over the station mark, spread the legs to about three feet apart, and move them until the *vertex* of the legs is exactly over the mark. A small stone dropped, or a plummet suspended from a hook, immediately under the vertex, will indicate when this is effected. Being satisfied as to the position of the instrument, press the legs firmly into the ground, and proceed to level it. Two spirit levels are generally fixed to the upper plate of the instrument, at right angles to each other. The four parallel plate screws, G, act upon this circle. Bring one of the spirit levels into a position parallel, if I may say so, with two of those screws that stand opposite or diagonally to each other. Now, by raising one screw, and lowering, at the same time, its opposite, the position of the horizontal circle will be changed. Continue working these screws until the bubble of the spirit level acted upon, rests in the middle of the open space: then work the other pair of screws, until a similar effect is produced upon the other spirit level. The adjustment of the latter will, however, throw the other level somewhat out, rendering a return to it necessary. The horizontal circle is not truly level, or parallel to the horizon, until the bubbles of both spirit levels stand in the middle of the open spaces during a revolution of the instrument.

I have been particular in describing the above mode of levelling by means of vertical screws, because it is the principle commonly applied to theodolites; but I strongly recommend that all instruments should be levelled according to a method, introduced within the last few years by, I believe, Mr. Gilbert. The improved manner of levelling is by means of two horizontal screws acting upon the *spindle* of the instrument, in its socket; which action of the screws is resisted by two spiral springs. This I consider to be a very great improvement upon the old method of levelling; and having had a theodolite so improved in use for some time, I can speak of its merits from experience. It causes a great saving of time and trouble.

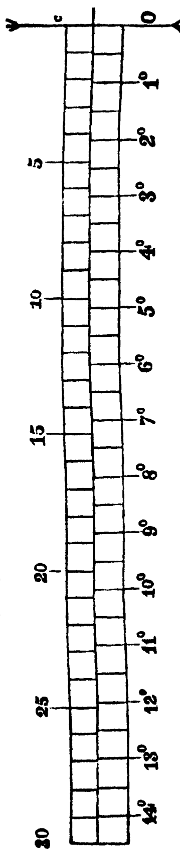
An angle is measured with the theodolite thus:—



S is the station of the instrument: required the angle between the windmill *n* and the spire *w*. Plant the theodolite over the station point, as directed above, carefully attending to all the instructions just given. Make zero of the vernier scale to coincide with zero of the horizontal circle, and fix them so by tightening the screw, P. Place the intersection of the hairs in the telescope on the windmill *n*, and fasten the clamping screw, A; then, if the object *n* is not found to be exactly covered by the point where the hairs cross each other, turn the micrometer screw, B, which will enable you to fix it with the utmost precision. This effected, loosen the screw, P, which will release the index or vernier plate from the horizontal circle; then turn the upper part of the instrument until the cross hairs cut the object *w*. The vernier micrometer screw, N, enables this to be done very exactly, on tightening the screw, P. Then the number of degrees and minutes passed over by the vernier, or index, shows the measure of the angle.

The vernier scale, which is applied to instruments both for measuring angles and distances when great accuracy is required, must now be noticed. The horizontal circles of ordinary theodolites are divided to half degrees, and are most convenient when numbered from zero to 180°, as recommended for the prismatic compass. Now, without such a contrivance as the vernier, we can only guess at the number of minutes, when the index does not exactly agree with one of the subdivisions; but, by means of a vernier, we are enabled to read off an angle on the circle of an ordinary theodolite to a single minute; and may, if the horizontal circle be very large, read off to twenty seconds with the greatest certainty.

The construction of this ingenious contrivance is simple. Suppose we want to read off to one minute.—Take the length of 29 half degrees on the horizontal circle, and divide that distance into 30 equal parts; this forms the vernier, which is marked for convenience, 5, 10, 15, 20, 25, 30, from one end, or the zero. Place the vernier to the horizontal circle, so that zero of the former may be in contact with zero of the circle; then the last division, marked 30, of the vernier will, of course, agree with 14½°, or 29 half degrees of the circle. And the proportion of each division of the vernier, will be to a division of the circle, as



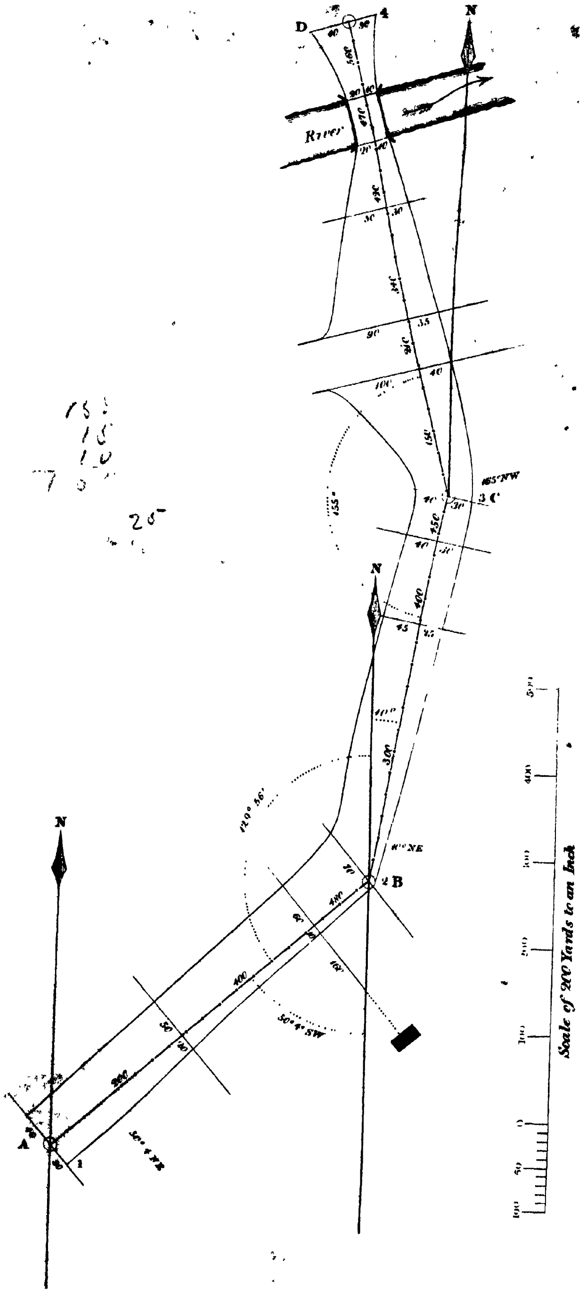
VERNIER SCALE—*to one minute of a degree.*

14½ degrees, or 29 half degrees.

29 to 30. If the zero of the vernier be moved from the zero of the circle, then the first coincidence that takes place between a division of the vernier with one on the circle, indicates the number of minutes passed over. To read off an angle on the horizontal circle, use a magnifying glass, and notice how many degrees have been passed over by the zero of the vernier: for example, let us suppose that the arrow at zero of the vernier has passed the 21st degree of the circle; then, for the number of minutes in addition, look along the vernier, until one of its divisions is found to agree exactly with a division on the circle below it. You find, we will suppose, that the 14th division of the vernier does so: then the angle is 21° 14′.

A careful and minute description of the various parts of the theodolite, with instructions for their adjustment before proceeding to the field, will be found further on; aided by which, an intelligent person may, with a little practice, rectify every derangement to which the instrument is liable.

VI.



D
4
N
River
165°NW
3 C
155°
N
129° 56'
6° NE
2 B
50°4' SW
A
1
Scale of 200 Yards to an Inch

SECTION VI.

OF ROAD SURVEYING WITH THE THEODOLITE AND CHAIN, AND PLOTTING THE SURVEY.

Formerly, surveyors made much use of the compass which is attached to the theodolite, when engaged in surveying roads, rivers, boundaries, and performing such work as is now generally termed *traversing;* this mode is similar in principle to that of surveying with a prismatic compass, as described in Section II., but more accurate, owing to the superiority of the theodolite. The needle, however, cannot always be depended upon; as, besides being affected by local attraction,* it is subject to a trifling variation at different times of the day. This imperfection in the needle has induced most surveyors to abandon the expeditious mode of working by it, when using the theodolite; they now generally practise one which leaves them independent of the compass, save to note the cardinal direction of their station lines. Both methods shall be described.

The following implements are required for the survey of a road.

* One of my brother officers lost a whole day's work, at a very important period of the Peninsular war, in consequence of iron ore being abundant on the banks of the Zezere river. When he came to plot his numerous bearings, taken during a busy day, nothing could be made of the work.

A measuring chain.

Ten arrows.

Two staves, for placing as marks at the stations.

A field book, for registering the observations and measurements.

Land surveyors universally use the Gunter chain, of 66 feet, divided into 100 links; which is very convenient when the contents of an estate or parish are to be given in acres, roods, &c.: but for our purpose, a chain 100 feet long is to be preferred, the object being to obtain lineal, and not superficial measure. The 100 feet chain is divided into links of one foot each; and certain brass marks fixed on it, at ten feet distance from each other, show at once any number of feet less than 100. The arrows are stout pins of iron wire, about twelve inches long. The field book, of the size of a common memorandum book, has upon every alternate page two lines drawn lengthwise down the middle, at about three-quarters of an inch apart. The blank page adjoining is used for making notes.

Let A (plate VII.) be the point upon a road for commencing a survey with the theodolite and by the needle. Set up the instrument very exactly over the point marked, level it carefully in the manner already described, and place zero of the vernier to agree with zero of the horizontal circle; then, by means of the screw, P, fix the two plates together. Now turn the instrument on its axis, until the marked end of the needle settles exactly at the division in the compass box at N, or north, marked 360 or 180, and tighten the clamping screw, A; then, if the needle does not accurately agree with the 360 or 180 (as the case may be, for theodolites are differently numbered,) in the compass box, use the micrometer or tangent screw, B, which will adjust it to the greatest nicety. All is now ready to take a bearing.

Place a staff or bandrol at the point B,* where the road makes a bend, and examine your instrument again to see, 1st, that the index or zero of the vernier corresponds with zero of the horizontal circle; 2nd, that this circle is truly level; 3rd, that the needle points exactly to the division at N; and, lastly, that the clamping screw is firm.

To take the bearing of the staff planted at B, loosen the screw, P, which connects the vernier plate with the horizontal circle, and turn the vernier plate, with the upper portion of the theodolite, on its axis; continue this until the staff at B is seen through the telescope: then tighten P, and turn the micrometer screw, N, at the same time, raising or depressing the telescope as much as may be requisite. Fix the intersection of the hairs in the telescope precisely on the *bottom* of the staff at B. The divisions in the compass box will indicate how many degrees have passed the *stationary* needle; but we must refer to

* The letters A, B, &c., are not necessary in surveying, to mark the stations on a road; ⊙ 1, ⊙ 2, &c., is sufficient that for purpose. Letters are used here to facilitate the descriptions.

the vernier for the exact measure of the angle, that a line from A to B forms with the meridian, which meridian is represented by the direction of the needle. On examination, we find that the zero of the vernier is something past the 50th degree of the circle; and looking along the vernier, through the magnifying glass, it appears that the 4th division on it agrees with a division of the circle. Thus, the bearing is 50° 4′; and as we perceive, looking at the needle, that ⊙ B lies to the right, or eastward of north, we put down 50° 4′ N.E., ⊙; the latter mark being to distinguish the station angle or bearing, as the case may be, from any other angle or bearing that may be observed at the same time. The first entry in the field-book is made at the bottom of the the page, proceeding upwards. (See the specimen of a field-book.)

The next step is to measure the distance from A to B. To do this, an assistant takes one end of the chain, and proceeds towards B, until desired to stop by the person holding the other end. The latter places himself over the point where the instrument stood, and motions the chain leader, who is facing him, to move right or left, until he is exactly in a line with a staff at B. The chain is then drawn tight, and left on the ground while any off-sets, that may be necessary, are taken. Off-sets are measurements laterally from the chain, and usually perpendicular to it, to determine the distance of a house, fence, gate, &c., from the chain line. For instance,

the breadth of the road at A (plate VI.) is found by measuring, or taking an off-set at right angles with the chain line to the fences, on each side of that point, namely, to the right, 30 feet, and to the left, 40; which are entered in the field-book at A. Off-set-measurements may be made by pacing, with a wooden-rod, or a measuring tape, according to the degree of accuracy required. Pacing does very well for military plans, and the eye is a sufficient guide for the direction, so as to go perpendicularly to the chain line.

Let me observe here; that the space between the two ruled lines of the field-book represents the chain. Bearings or angles taken during the survey, together with all distances measured between stations, are entered in this space; but all off-sets from the chain, are put down outside the ruled lines.

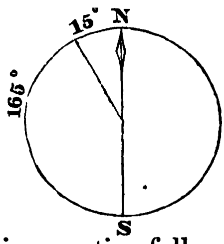
To proceed with the measurement towards B. The chain leader has ten arrows, one of which he sticks into the ground at the end of the chain, or makes a cross if the road is hard, and lays the arrow down: he then draws the chain forward, giving it a cast to the right, so as to keep it from disturbing the arrow he has placed. When the chain follower comes within a few feet of the arrow placed at the end of the first chain, he calls "Halt," places the leader in line with B, and takes up the arrow. At two chains, or 200 feet, from A, a second off-set is taken, namely, 20 feet on the right, and 50 feet on left; which are entered, as seen in the field-book.

Thus the measurement proceeds—the leader always depositing an arrow at the end of every chain, which is taken up by the follower. At the end of ten chains, the leader will have expended all his arrows, which have become transferred to the follower. When the eleventh chain is measured, the latter runs forward, and restores the ten arrows to the leader, who should count them to see that he has ten, and place one to mark the eleventh chain; 1000 is then entered in the chain column, and so on to 2000, 3000, &c.; and on arriving at the end, he has only to count the arrows in his hand, adding whatever number of feet are indicated by the brass marks upon the chain; and in this way he will rarely make any mistake.

At 400 feet, there is an off-set to a house standing at the distance of 160 feet from the chain. Be it observed, that all off-sets are to be put down at their distance from the chain: here, for example, we have ten feet to the fence, and 150 from thence to the house; but we enter 160, the distance of the house from the chain.

When the measurement of the first station is completed, the theodolite is set up at ⊙ 2 (B), care being taken to place it vertically over the hole in which the staff stood, which may be ascertained by dropping a stone from the vertex of the legs of the instrument, or by a plummet, as already mentioned. A staff is to be planted at the next bend of the road, C, and the instrument adjusted; when the bearing of C, or $\odot$ 3, is to be taken, and the chaining proceeds as before.

When observing at $\odot$ 3 (C), $\odot$ 4 (D) is found to bear west of the meridian. It will be recollected that when using the surveying compass, all bearings lying on the west side of the meridian were reckoned from the *south* pole of the needle, round towards west and north; and the same method had better be adhered to still. The horizontal circle of a theodolite is commonly divided in the manner recommended for the surveying compass, namely, into twice 180°, and the circumference of its compass box in the same way, to correspond. However, the learner will find that it does not signify, whether the bearing of D, in this instance, be entered as 15° N.W., or 165° N.W.; the same line must be produced in plotting, whichever way the bearing has been put down; for a bearing always being taken from the meridian, 15° N.W. can only be plotted from N., while 165° N.W., must necessarily be taken from S. A little consideration will make this quite clear to the student, who will in practice follow *one* method of entering bearings, adopted according to the manner in which the circle of his instrument may be divided.



Some circles being numbered (as already observed) from 0 to 180°, and others from 0 to 360°.

But returning to the survey.—Previous to our arriving at D (⊙ 4), a bridge is passed, when if an off-set be taken at each margin of the stream, its width is determined.

The student, who understands what has been said thus far, will readily perceive that he has no need to set the instrument up at every station: thus, instead of taking the bearing of B from A, he may at once proceed to B, and taking the bearing of A, which is here 50° 4′ S.W., he enters at ● 1 in the field-book as 50° 4′ N.E., being the alternate angle, or *opposite bearing*. [See Section IV., where this is fully explained.] The bearing of C is then taken, and entered in the field-book as before. After which the instrument is removed to D, from whence the bearing of C is taken, and so on.

Enough has now been said as a guide for acquiring the method of surveying a road by the needle: I shall, therefore, merely observe in addition, that when a very exact survey is required, the kinds of fencing are noted, and gates, trees, &c., are to be put in. For these, and various other objects noticed in a plan, certain conventional signs are used, which will be detailed when plan drawing is treated of, to which branch they properly belong.

TO LAY DOWN OR PLOT THE ABOVE SURVEY UPON PAPER.

I shall first describe a method of plotting it, analogous to the one used for military sketching, as given in Section II., which will prepare the student for comprehending a much superior mode of performing the operation, to be noticed hereafter, when a minute description of the best protractor that I am acquainted with will be given.

It will readily be perceived, that bearings taken accurately to minutes of a degree with a theodolite, will avail us little, unless we have likewise the means of plotting them with equal accuracy. This we are enabled to do by means of a protractor, furnished with a vernier, of a circular or semicircular form. We will suppose the learner to be provided with one of the latter shape.

Draw a line, N S, upon the paper, to represent the meridian of A (See plate VI.), mark a point upon it for ⊙ 1, A. Apply the protractor so as for its base or diameter to lie along the meridian line, having its centre at the station point, and set the vernier to the first bearing entered in the field-book, namely, 50° 4′—or this may be done previous to placing the protractor: draw a fine line on the paper along the arm of the protractor from ⊙ 1, which line defines the direction of ⊙ 2, B, lying 50° 4′ N.E. of the meridian. Next, from any scale of equal parts selected for the survey, take in the compasses 480, being the whole length measured to B;* this distance taken along the line just drawn,

* A good method is to divide a slip of paper very accurately according to the intended scale, and apply it to the chain line; this is an expeditious mode, but not quite so exact as that of taking distances from an ivory *diagonal* scale with a pair of fine compasses.

fixes ⊙ 2, B. Through this point, draw a line, N B, parallel to N A S, for the meridian of ⊙ 2. After which, set the protractor to 10°, apply it to the line N B, and lay off B C. Take 450 from the scale, and fix the point C, ⊙ 3. Thus continue until all the stations are laid down. When satisfied that these are correctly fixed, the off-sets are to be plotted: here a slip of paper divided according to the scale is extremely useful. First, mark a point at 200, and another at 400 feet from ⊙ 1. Turn the slip of paper at right angles to the line A B, and at the point A, set off 40 and 30, as seen in the plan: then at 200 feet, again use the slip scale, and mark 50 on the left, and 20 on the right: at 400 feet, 60 and 10. Join these points of the cross measurements, or off-sets, and the boundaries of the road will be correctly shown.

The road given in plate VI., being accurately drawn to a scale of half an inch to 100 feet, namely, the large diagonal scale on the ivory protractor—a comparison of it with the description given, will, it is hoped, render the whole process perfectly intelligible.

SECOND METHOD OF SURVEYING A ROAD, OR TRAVERSING.

Having planted the theodolite at the point from whence it is intended to begin a survey, and the several adjustments having been made, set the vernier at zero, or 180°, (the horizontal circle being divided into twice 180°), and clamp the vernier plate; then turn the instrument until the magnetic needle agrees with the N. and S. points of the compass. Let the point A (plate VI.) represent the station of our instrument, A N the meridian of that point, and B a bandrol, where the road makes a turn. The angle, N A B, being measured, is found to be 50° 4′ N.E. *Keep the vernier clamped at that angle*, remove the theodolite to B, and, without unclamping, direct the telescope on a bandrol fixed at A; this effected, and keeping the instrument firmly clamped by the screw A (plate V.), loosen the vernier plate, and adjust the telescope on a bandrol at C, the third station; the reading off will then be 10°; for, previous to unclamping the vernier plate, the reading was 50° 4′, and 129° 56′ completed the 180°: the new reading off is therefore the amount of the angle N B C, or 10°. Clamp that angle, remove the theodolite to C, and adjust the telescope on B; then release the vernier plate, and direct the telescope on D, when the reading will be 165°, viz., 155° added to the 10°; and so the survey proceeds.

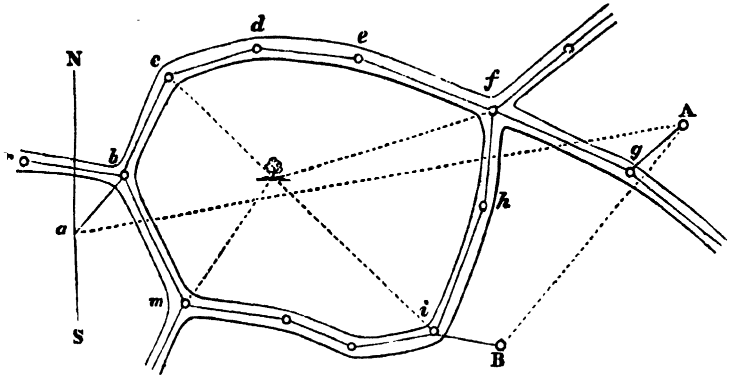
It will be perceived that, after the adjustment of the needle at the first station, it becomes no longer necessary, except to point out the directions of the several station lines; and hence this method has a great superiority over that of surveying by the needle, in the manner we have seen. But the advantage does not end here, for we have no occasion to make use of the magnetic meridian from which to measure our angles; any line will do equally well; so that, when filling in a survey, it is usual to select some fixed and conspicuous point of the survey, from which to measure the first angle. The several station lines of the road survey have then reference to an assumed working meridian, viz.—the line between our first station on the road and the conspicuous object chosen; and the compass is only used to denote the directions of our station lines, rendering us independent of all local attraction; which, as I have already remarked, sometimes very materially affects the needle.

In surveying a road, any remarkable object that may be visible from several stations, and not more than from half to three-quarters of a mile distant, that the intersections may not be too acute, should have its bearing frequently taken as a check upon the work; for afterwards, in plotting, when the several bearings to an object unite at a point, the proof of accuracy is complete and satisfactory: indeed, some such check is at all times necessary. When any check bearings are taken, it is usual to enter them in the field-book before the forward or station bearing, to avoid mistake; but it is better to place this mark (⊙) at all times against the bearing, or angle, which gives the direction of the road or the line on which you measure.

In order to be able to resume an incomplete survey, a mark must be made at the last station by cutting a cross in the sod, or driving a strong peg into the ground. And it is necessary, both on beginning and ending a day's work, to take angles between the back or forward stations, and any two fixed points that may be visible.

The following example is taken from Mr. Simms's treatise on instruments; and I recommend it to the student's attention, as highly useful in showing how a check is maintained over a road survey, so as to preclude a possibility of error.

Let the diagram in the next page represent a survey of roads to be performed with a theodolite and chain. Commencing on a conspicuous spot, *a*, near the place where two roads meet, the theodolite must be set up and levelled, the upper and lower horizontal plates clamped at zero, and the whole instrument turned about until the magnetic needle steadily points to the NS line of the compass-box, and then fixed in that position by tightening the clamping screw A [See plate V., page 21]. Now release the upper plate, and direct the telescope to any distant conspicuous object within or near the limits of the survey, such as a pole purposely erected in an accessible situation; that it may be measured to, and the instrument placed upon the same spot at a subsequent part of the operation, as A and B, and after bisecting it with the cross wires, read both the verniers of the horizontal circle, and enter the two readings in the field-book; likewise, in the same manner, take bearings, or angles, to all such remark-



able objects as are likely to be seen from other stations, as the tree situated on a hill; and lastly, take the angle to your forward station, *b*, where an assistant must hold a staff for the purpose, on a picket driven into the ground,* in such a situation as will enable you to take the longest possible sight down each of the roads that meet there. In going through the above process, at this and every subsequent station, great caution must be used to prevent the lower horizontal plate from having the least motion after being clamped in its position by the screw A.

Next measure the distance from *a* to *b*, and set up the instrument at *b*; release the clamp-screw A *only*, not suffering the upper plate to be in the least disturbed from the reading it had when directed at

* A picket should always be left in the ground at every station, in order to recognise the precise spot, should it afterwards be found necessary to return to it again.

a to the forward station *b*; with the instrument reading this forward angle, turn it bodily round, till the telescope is directed to the station *a* (which is now the back station), where an assistant must hold a staff, tighten the clamp-screw, A, and by the slow-motion screw, B, bisect the staff as near the ground as possible, and, having examined the reading, to see that no disturbance has taken place, release the upper plate, and, setting it at zero, see if the magnetic needle coincides, as in the first instance, with the NS line of the compass-box; if it does, all is right, if not, an error must have been committed in taking the last forward angle, or else the upper plate must have moved from its position before the back station had been bisected; when this is the case, it is necessary to return and examine the work at the last station. If this is done every time the instrument is set up, a constant check is kept upon the progress of the work; and this indeed is the most important use of the compass. Having thus proved the accuracy of the last forward angle, release the upper plate, and measure the angles to the stations *m* and *r*, and, as before, to whatever objects you may consider will be conspicuous from other places; and lastly, observe the forward angle to the station *c*, where the theodolite must next be set up, and measure the distance *bc*.

At *c*, and at every succeeding station, a similar operation must be performed, bisecting the back station with the instrument reading the last forward angle; then take bearings to every conspicuous object, as the tree on the hill, the station A, &c., which will fix their relative situations on the plan, and they afterwards serve as fixed points to prove the accuracy of the position of such other stations as may have bearings taken from *them* to the same object; for, if the relative situations of such stations are not correctly determined, these bearings will not all intersect in the same point on the plan. The last operation at each station is to measure the forward angle. In this manner proceed to the stations *d*, *e*, *f*, *g*, &c., and having arrived at *g*, measure the angle to the pole A, as to a forward station, and, placing the theodolite upon that spot, direct the telescope to *g*, as a back station, in the usual way; this done, release the upper plate, and direct the telescope to the *first* station, *a*, from which A had been observed, and if all the intervening angles have been correctly taken, the reading of the two verniers will be precisely the same as when directed to A from the station, *a*; this is called *closing* the work, and is a test of its accuracy, so far as the angles are concerned, independent of the compass needle. If the relative situation of the conspicuous points, A, B, &c., were previously fixed, there would be no necessity to have recourse to the magnetic meridian at all, as a line connecting the starting point, *a*, with any visible *fixed* object, may be assumed as a working meridian; and, if it be thought necessary, the reading of the compass needle may be noted at *a*, when such fixed object is bisected; and upon the theodolite being set to the reading of this assumed meridian, at any subsequent station, the compass needle will also point to the same reading as it did at first, if the work is all correct, and no local attraction influences the compass.

While the instrument is at A, take angles to all the conspicuous objects, particularly to such as you may hereafter be able to close upon, which will (as in the above instance) verify the accuracy of the intervening observations; having done this, return to *g* and *f*, &c., and proceed with the survey in the same manner as before, setting the instrument up at each bend in the road, and taking off-sets to the right and left of the station lines; arriving at *i*, survey up to, and close upon, B; then return to *i*, and proceed from station to station till you arrive at *m*, where, if the whole work is accurate, the forward angle taken to *b* will be the same as was formerly taken from *b* to *m*, which will finish the operation.

SECTION VII.

GENERAL OBSERVATIONS ON SURVEYING.

Surveying may be defined, the art of representing a country, or any portion of the earth's surface, upon paper, in such a manner that we may be able, by means of a scale, to measure the horizontal dimensions of its features; as territorial boundaries, lakes, rivers, forests, roads, &c.

"Accurate surveys of a country are universally admitted to be works of great public utility, as affording the surest foundation for almost every kind of internal improvement in time of peace, and the best means of forming judicious plans of defence against the invasions of an enemy in time of war; in which last circumstance, their importance usually becomes the most apparent. Hence, it happens, that if a country has not actually been surveyed, or is but little known, a state of warfare generally produces the first improvements in its geography: for in the various movements of armies in the field, especially if the theatre of war be extensive, each individual officer has repeated opportunities of contributing, according to his situation, more or less towards its perfection; and these observations being ultimately collected, a map is sent forth into the world, considerably improved indeed; but which being still defective, points out the necessity of something more accurate being undertaken, when times and circumstances may favour the design."—*Introduction to an Account of the Trigonometrical Survey of England.*

The foundation of every survey is a base line; and upon the accuracy with which the length of the base is obtained, the correctness of the entire survey must depend.* The measurement of a base, then, is not only the primary, but also the most important work to be performed. Various methods have been pursued to effect this object.

Previous to the measurement of the Hounslow base, deal rods were considered very good for the purpose, and had been extensively used on the

* The length of the base measured on Hounslow Heath, for the grand Trigonometrical Survey of England, in 1784, was, when reduced to the level of the sea, 27404·1037 feet. Three modes of measuring were tried, viz., with deal rods, with a steel chain of peculiar construction, and by means of glass tubes. The uncertain expansion and contraction of the deal rods, was found to produce a very fallacious result. The steel chain does not appear to have had a fair trial upon this occasion. The method proposed with glass tubes obtained the preference. Accordingly, the measurement took place with these, and was conducted in a scientific manner, with all the care due to so important an operation. In 1791, a careful measurement of the same base was made with the improved steel chain, which only differed from the original one performed with glass tubes, by about 2¾ inches. Subsequently, in 1794, a base of verification was measured on Salisbury Plain, which varied only about 3½ inches from its computed length.

Continent; but experiments made on that occasion proved their unfitness, owing to the uncertainty of their expansion; perhaps, however, our more humid climate may have produced a greater effect upon them, than the comparatively dry atmosphere where they had before been tried; and it appears, from the account of the operations on Hounslow Heath, in 1784, that the season was a very wet one. On the whole, if I may presume to offer an opinion in the matter after their condemnation by men of so much science, I should still advise the use of deal rods under other circumstances, and where glass tubes and steel chains, such as were used on the occasion abovementioned, with all the vast preparation made for their application to the object in the most perfect manner, cannot be had; and, more than all, when the contemplated survey is not of the most important character.

Indeed, Mr. Dalby, the associate of General Mudge in the grand survey, recommends the use of such rods on ordinary occasions; and as I look upon that gentleman's opinion with respect, I shall quote from his work on Mathematics what he says on the subject, concurring, as I do, with his views, and not being aware of any better plan to substitute for the one he proposes.

"But the most difficult and tedious operation connected with a survey, is that of measuring a base-line accurately. We shall therefore recommend a perusal of the account of the *Trigonome-*

trical Survey, to those who may engage in an undertaking of this kind, when great exactness is required. A base for common surveys may be measured with a 20 *feet deal rod:* for this purpose, a rope, not less than 100 *yards*, should be stretched very tight along the ground; the rod must then be applied to the rope, and its extremity may be marked with a small pin stuck in the rope, to preserve the distance while the rod is removed. When the measurement is carried on to the extent of the rope, a peg should be driven in the ground, and a notch cut on its top, exactly under the end of the last rod. The rope must then be taken up, and stretched again in the direction of the base, and the measurement continued as before.

"When the measurement is carried over hollows or ditches, it may be necessary to support the rod in the middle: it should not, however, be made very slender.

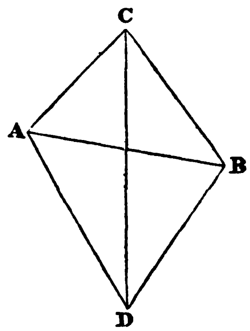
"If rising grounds intervene, the slant distances must be measured as hypothenuses, and afterwards reduced to the corresponding horizontal lines: the elevations and depressions may be taken with a theodolite which has a vertical arc.

"It may be necessary to observe, that 20 *feet* should be transferred to the rod from a *standard measure.* And with respect to expansion and contraction, it is pretty well known that well-seasoned deal is subject to very little alteration, while it is kept dry.

"If a measurement of this kind be performed with tolerable care, we may safely conclude, there will not exist an error of more than one-tenth of an inch in each rod of 20 feet, or 26¼ inches in a mile. Supposing, however, the accumulated errors amount to five feet in a base of two miles, and that a series of triangles, whose sides are about three miles, to be determined from such a base—then combining the probable errors from observations made with a theodolite—the uncertainty in a direct distance of 20 miles from the base, cannot amount to 30 yards. Erroneous as this may be considered, we believe most of the county maps have been laid down from operations less accurate."

In ordinary surveys, it is not necessary to enter into calculations, on account of the sphericity of the globe; nor indeed into many other niceties, such as would be imperative, were the object to measure an arc of the meridian, or perform any other grand trigonometrical operation. On common occasions it suffices to consider the earth as a plane or flat surface, and all the sides of the triangles as right lines, instead of curves.

The ground having been selected for measuring a base, and this operation performed with all the accuracy the means will admit of, the next step is to choose the most eligible points for carrying on the triangulation—a survey being conducted by means of a series of triangles, of which the base line forms one side of the first. With this view, conspicuous situations are fixed on, as the tops of hills, church towers, &c. These primary stations ought generally to be of a distance from each other, bearing some proportion to the length of the base and extent of the proposed survey. For instance, if the base be two miles, and extent of the survey 15 or 20 miles, the sides of the triangles may be from two to four miles; much, however, must always depend on the relative positions of commanding points for stations, and on the two first triangles of the survey. For example:—Suppose A B to represent a base line, and that C and D are eligible stations, forming two triangles, A C B and ADB. Knowing the length AB, and the angles at A and B, the length of C D is found by an easy calculation in trigonometry; and that line becomes nearly as good a base in point of measurement, as A B, while it possesses the advantage of being longer, and thus enabling us to increase the sides of our triangles.*



Wherever the instrument is set up, observations should be taken to all remarkable objects; these being repeatedly intersected, furnish a check on the

* This method of obtaining a longer base, as it may be termed, becomes useful when a base is measured on low ground between hills, as must frequently be done; such situations being often level, and suitable for the purpose.

work as it proceeds, and their several positions are furthermore determined for future use.

When possible, all the three angles of the principal triangles should be observed; then, as the sum of the three angles ought to be 180°, we are enabled to judge of the accuracy of the observations, and in some degree of the perfection of the instrument used.

The sides of all the principal triangles should be *calculated*, and laid down by means of beam compasses—as protraction by the *sides* is always more correct than by the *angles*. In triangles on a large scale, an error of a single minute, in protracting an angle, would sensibly affect the length of the sides.

As it is impossible to avoid some degree of error in taking angles, we should endeavour so to order our operations that the error may have the least possible influence on those sides, the exact measure of which is the object to be obtained.

When the base cannot be equal to the side or sides sought, it should be as long as possible; and the angles at the base should be nearly equal.

Sometimes it occurs that the three angles of a triangle cannot be observed; in that case, the angle obtained by intersection should be as near as possible a right one. Acute intersections are at all times to be avoided.

The fewer the principal stations, the less will be the labour of the survey; it will also be more accurate, and less liable to mistakes while in the field, or errors when plotting the work at home.

Military men generally fill in the principal triangles by means of the pocket sextant and surveying compass, when the survey is not required to be minutely exact in all its details.

These general observations might be multiplied to an unlimited extent; and yet, after all, when a survey is to be undertaken, the surveyor must depend chiefly on his own judgment, to lay out the work to the greatest advantage, according to the nature of the country, and other circumstances that will affect his operations.

SECTION VIII.

METHOD OF CONDUCTING A SURVEY.

It may now be of service, if I proceed to furnish an example of the most simple manner in which the survey of a tract of country may be commenced and carried forward. I shall suppose the survey such as might be wanted for military purposes, and that a small theodolite and common measuring chain are to be used. (Plate VIII.)

The selection of a base line is the first consideration; and on examination, the direction of A B, along a piece of level ground, is found the most eligible. The next object is to choose commanding points for stations, so situated with respect to each other that good triangles may be formed; that is, sufficiently wide apart, and forming angles not too acute. These important matters being arranged, the base, A B, must be carefully measured three times over, and the mean taken, which is 3574 yards.

Marks, such as small flags, having been placed at C, E, and F, the most favourable points on the ridge running parallel to the river; also at H and G: the theodolite is set up at A, and the following angles taken, namely, C A E, C A F, C A B, B A G, and B A H. These may be entered in the field-book thus:—

At A.

From C to E,	65° 50′	(Angle C A E.
C to F,	96 40	„ C A F.
C to B,	126 45	„ C A B.
B to G,	22 25	„ B A G.
B to H,	80 10	„ B A H.)

The instrument is then taken to the other end of the base, and angles are observed at B.

At B.

From A to E,	40° 20′	(Angle A B E.
A to F,	100 2	„ A B F.
G to H,	31 40	„ G B H.
G to A,	64 0	„ G B A.)

It should be observed, that when time permits, it is usual to take all such angles three times over, each time turning the circle of the theodolite, for greater correctness, and as a check against error. In this case, an entry would be made thus:—

At B.

	1st Obs.	2nd Obs.	3rd Obs.	Mean.
From A to E	40° 20′	40° 19′	40° 21′	40° 20′
A to F	100 2	100 1	100 3	100 2

With respect to the circle of the instrument, you may begin to work from any part of it; by which, should the dividing not be very perfect, the errors compensate each other; and to save time in the field, enter the readings as you obtain them from the circle, and work out the quantity for each angle at home. Suppose you commence taking angles, with the index showing 50° 10′, the entries at B would be thus, to agree with the preceding example:—

	From A to E.		From A to F.	
Index at 50° 10′.	1st observ.	90° 30′	1st observ.	150° 12′
	2nd ditto	90 29	2nd ditto	150 11
	3rd ditto	90 31	3rd ditto	150 13
	Mean . .	90 30	Mean . .	150 12
	Deduct . .	50 10	Deduct .	50 10
		40 20		100 2

The requisite angles having been observed from each end of the base, the instrument is moved to E, and angles taken, namely:—

At E.

From A to C,	59° 10′	(Angle	A E C.
A to L,	87 0	„	A E L.
A to D,	142 30	„	A E D.)
A to M,	199 20		
A to F,	236 40		
A to B,	281 15		

Next move to C.

At C.

From L to D,	51° 20′	(Angle	L C D.
L to E,	84 5	„	L C E.
L to A,	139 5	„	L C A.)

The instrument is then taken to F.

At F.

From	B to A,	49° 53′	(Angle	A F B.
	B to E,	75 30	„	E F B.
	B to D,	103 2	„	D F B.
	B to M,	155 12	„	B F M.)

After which, angles are observed from other stations.

Previous to plotting, I recommend a diagram or figure to be drawn, representing the base line, and the several triangles; of these, it is a good plan to make a list, thus:*—

Triangle A E B.		*Triangle* A C E.		*Triangle* A B F.	
Angle A,	60° 55′	Angle A,	65° 50′	Angle A,	30° 5′
B,	40 20	C,	55 0	B,	100 2
E,	78 45	E,	59 10	F,	49 53
	180 0		180 0		180 0

To lay down the triangles: First draw a line on the paper, and take from the scale you intend to use, 3574, for the number of yards in the base; lay off this distance along the line, and one end of the length so marked on the line will be A, the other, B.

A consideration next arises whether the triangles shall be protracted by the sides or the angles; if by the sides, their lengths are worked out by means

* Two angles of any triangle being known, the third angle is their supplement to 180°

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of plane trigonometry, and then laid down; for example: In the triangle, ABE, one side, namely the base, AB, is given, and the three angles; by means of which we are enabled to find the other two sides, AE and EB, by an application of the first case of trigonometry. The distances so found have then only to be taken from the same scale as the base, and the triangle, AEB, is easily constructed. Again, in the triangle, BEF, we have the side, EB (as just found), and the angles, to find EF and BF. Also in the triangle, ACE, the side, AE, has been found, which, with the angles, give AC and CE. The other triangles are obtained in the same way. Thus, every side whose length is found becomes a base line for a succeeding triangle; and in this way a succession of triangles may be carried over the face of a country. Such is the method pursued in a regular trigonometrical survey.

But in a survey of small extent, and especially when time, as during warfare, becomes an object of importance, the triangles may be protracted by the *angles*. Indeed, when the sides of the triangles do not exceed two or three miles, and the scale not more than four inches to a mile, a good protractor of five or six inches radius enables us to lay down the triangles with sufficient accuracy and great dispatch.

To commence then protracting by the angles: Referring to page 53, we find that, having the theodolite placed at A, our first set of angles was measured *from* C, to E, F, and B; therefore, the first step now must be to fix the direction of C. To do this, we have only to look what angle is formed by C with the base, or in other words see how many degrees the angle is from C to B. Accordingly, we set the vernier of our semicircular protractor to 126° 45′ (page 53), namely, the angle CAB; and then place it so that its centre shall be at the point, A, while its straight base agrees with the base line, AB. A line is then drawn along the arm of the protractor, which line will determine the direction of C, forming an angle, CAB, of 126° 45′. This done, we are prepared to lay down the directions of E and F. The angle from C to E is 65° 50′; set the protractor to that quantity, but its position requires to be changed, as the straight base must now agree with the line, AC, while its centre continues, as before, at A. A line is now drawn, forming the angle, CAE; and in the same manner the direction of F is obtained, forming an angle, CAF, of 96° 40′. Next, for G and H, lay off from AB 22° 25′ for G, and 80° 10′ for H. Adjust the protractor on AB, with its centre at B, and lay off 40° 20′, the angle, ABE, and 100° 2′ for the angle, ABF; draw lines, BE and BF, which will intersect AE and AF, thus determining the points E and F. Afterwards, draw GB, making an angle of 64° with AB, and on GB, as a base, set off 31° 40′ for the angle, GBH; G and H will then be fixed by intersections with the lines, AH and AG.

Observe, when at A, the reason for taking angles from C towards B was to avoid the inconvenience of reading angles backwards on the horizontal circle of the theodolite, which would have been the case had we taken the angles to F, E, and C from B. The angles might, however, have been taken from B to G, then to H, and continued round to C, E, &c.; but the other way is most simple, and therefore easiest to be understood.

The angles taken at E are now to be protracted, together with those taken at C and F.

In the survey before us, we have E determined by observations from A and B. C, from A and E. F, from A, B, and E. D, from C, E, and F. The work then proceeds, taking the lines, AC, CD, DF, &c., as bases. Had it been desirable, we might have found the length of the line, EH, and worked from it as a base of greater length, and, consequently, furnishing a foundation for larger triangles.

When a survey is of limited extent—say, from eight to twelve square miles — I would suggest that the base be laid down on a small scale, and the angles protracted with the ivory protractor in the field. This is quickly done, and will be found an advantageous method by persons who have not much practice in surveying, and who are consequently liable to make mistakes when they come to plot from a field-book alone; but doing this is by no means to be understood as superseding the necessity of going over the whole protraction on a large scale, and more accurately afterwards.

After what has been said in the early part of the work, when treating of military sketching with the compass, it may be almost superfluous to dwell here on the manner of filling in these triangles; however, I shall say a few words upon the subject. Before entering into any details, I ought to observe, that in extensive surveys what are called *secondary* triangles are always formed within the great triangles, so as to subdivide each of them into several smaller ones, affording stations carefully determined, for intersecting the various objects contained within their limits. But in the kind of survey we have been considering, where the sides of the triangles do not exceed two or three miles, this proceeding is not followed; and something like what I am about to describe would be done in such case.

Referring to the little example in the plate, the course of the river would probably first engage our attention in the filling in; to obtain which I should place marks, as a, b, c, d, &c., and intersect them from the ends of the base, or by taking angles or bearings from any of the points previously fixed on the plan. The mention of bearings reminds me that a meridian line has not yet been laid down; this is to be done while the theodolite stands at one end of the base, by observing how the other end bears, or by using any other fixed points for the purpose. For instance, we find that

B bears from A 76° 10′ N.E. On the plan, then, it is only requisite to make the angle, NAB, 76° 10′, and the line, NS, becomes the magnetic meridian.

To return to the filling in of the survey; the points, f and k, the extremities of a little island, are fixed by angles from A, H, and E. To determine the situation of the bridge, take a bearing from A, and measure the distance. Do the same at B, to find the position of d. Observe, that an experienced surveyor takes the bearing of every object likely to be of use to him in filling in, at every station where the instrument may be set up; as a little foresight often saves him the trouble and loss of time occasioned by the necessity of returning to a station.

The skeleton of a survey being carefully laid down to the required scale, and found correct, portions of it must then be transferred by tracing, to pieces of paper of a convenient size to use in the field with the sketching case; when the hills, and every required detail, are put in with the aid of a surveying compass; the method of using which instrument has been fully shown in the first four chapters.

I do not here describe how the hills are to be sketched, and thus complete the plan; as a section must be devoted to the subject of sketching alone.

During the progress of a survey, advantage should be taken of any portion of level ground over which it may be carried, to mark off a convenient distance, which should be measured in precisely the same manner as that by which the length of the original base was obtained; then, a comparison between the length of such line, as measured, with its length on the plan — found either by computation, or by applying it to the scale used for the survey—will be a test of the accuracy of the work. A line measured for this purpose, is called a base of verification; and one or more, according to circumstances, should be made use of in all surveys.

Let me hope that enough has now been said to put the young military surveyor on a right track to acquire a knowledge of the art. My opinion is, that a work on surveying, to be of any use, must enter very much into particulars. Properly to initiate the beginner has been my aim; and I have sought to effect this object in a way to be understood by any one of common intelligence, who will take the trouble to think. Ordinary surveying is a very simple process, but to perform that process well requires both attention and experience. I trust this book will be found to contain all the information on the subject of surveying that the young officer will require; and should he be desirous of enlightening himself further, I recommend him to study the account of the trigonometrical survey of England.

I had almost forgotten to caution the student not to consider the examples given of military sketching and surveying as anything more than elaborate diagrams in illustration of the necessary descriptions; for instance, the method of conducting a survey, just described, is suited to a survey of twenty or thirty square miles, whereas the limits of our diagram do not contain more than six or or seven.

Apprehensive of drawing too largely on my reader's patience, I have avoided entering into greater detail with respect to filling in the triangles of a survey. I trust he will readily perceive, that the few examples given are merely to show the method to be pursued generally. And much as I am disposed to insist on the necessity of ample descriptions in a practical work, such as this is, yet, even on the subject of surveying, it may not be unwise to remember Voltaire's remark, that, "*le secret d'ennuyer est de tout dire.*"

SECTION IX.

ON PLAN DRAWING.—METHODS OF SHADING HILLS, ETC.

WE have seen, in the foregoing sections, the manner of proceeding in the field, in order to obtain the necessary measurements of a survey. It has also been shown how those measurements are laid down on paper, or plotted, so as to furnish a rough skeleton plan of the work. I shall now speak of plan-drawing, in its more limited sense, or the method of expressing upon paper, according to certain conventional rules, the various objects which the face of a country presents, and that are required to be delineated by the topographical draftsman: but of these, the drawing of hills alone demands serious attention, for all the rest give us no difficulty whatever.

Objects having elevation can only be expressed upon a flat surface, such as paper, by means of shade, or by being thrown, as it is called, into *relief*; and consequently we can only give this appearance of *relief*, or being raised above the surface of our paper, in a ground plan, to bodies whose forms present either slopes or curves; unless we depart from the principles that govern a ground plan, and give an elevation to such bodies, in the manner seen on very old maps and plans; a practice which has universally been discontinued, since the introduction of the present system of plan-drawing.

A hill therefore, presenting slopes, can, according to our conventional system of shade, be faithfully expressed on a ground plan, so as to convey an idea of elevation to all who are acquainted with the principles of plan-drawing; but we are unable to give the appearance of elevation to a building, because its walls are perpendicular. In reality, this is a matter of no consequence whatever, for the mind at once connects the idea of height with castles, churches, houses, &c.; and our method of shading hills, enables us, at the utmost, only to form a loose judgment of their height as compared to each other; for we cannot determine by it the actual elevation of any single hill. But for ordinary military purposes, an approximation to their *comparative* height is generally sufficient; and when for any particular object, it becomes necessary to determine the actual elevation of any point above the sea, a river, &c., we can ascertain it either by *levelling*, or by a problem in the application of trigonometry to the measurement of heights; and likewise, but with less accuracy, by means of the mountain barometer.

The theory most generally adopted, supposes the light to fall vertically upon the hills, in parallel rays; according to which steep slopes, receiving those rays at a more oblique angle than more gentle ones do, are therefore illuminated in a less

degree than the latter, and must be shown in a plan by a darker shade; while such portions of the ground as are horizontal, and receive, consequently, the rays of light perpendicularly to their planes, being thus illuminated in the greatest degree, are left without shade in a plan; but, as it is scarcely possible to fix a criterion for the depths of tint in shading to express ground, it is idle to suppose that, *practically*, the shading can ever be so exact as to enable us to measure by it the positive height of a hill.

I fear it is almost impossible, by means of plans and descriptions, to convey at once to the mind of a student a clear perception of our *conventional* system of expressing hills upon a plan; yet, if he will only have the patience to labour a little for himself, I think he may contrive to make it out. In the first place, he has to bear in mind that all distances shown upon a plan are horizontal ones; for instance, referring to plate IX., the line, H K, of the section, which is the hypothenuse of the right-angled triangle, H K N, is represented on the *ground plan* below by the line, H K, which is equal to H N in the section; and in same way, M B, a precipitous fall in the section, only occupies the space from M to B on the ground plan. Thus it is seen that the height of mountains or the depression of valleys exercises no influence upon the situations of objects in a plan. I may mention here that the level of the sea is, in great surveying operations, considered as the horizontal plane, to which all measurements must be reduced.

But as regards the expression of hills on a plan; suppose we are standing on one of a perfectly conical form, it is obvious that rain falling on its summit will trickle down towards the base in minute, diverging streams; — our vertical style of shading hills has been likened to these. The immediate purpose, however, of plate IX. is to show the principle upon which slopes are expressed by means of shade: this is made light or dark according as they are gentle or steep. The section given represents ground of varied character; A is on a level with the sea; from that point the hill has a steep rise to C, from whence it is somewhat more gentle as far as D; at E a descent begins, and continues to F, from whence there is a steep slope to G, and so on. I have endeavoured to make the shading of the ground plan to agree with the section: for instance, that from C to A is darker than between D and C. From D to E the ground is level, and therefore no shade appears. The slope from E to F, being greater than from D to C, is shaded darker: F G, being steeper, is made darker still, and the deep shade from M to B is equal to the shading of both of the slopes L K and K H.

I shall not fatigue my reader with any further description. He must now try and make out the corresponding parts of the ground-plan and section for himself. But perhaps he may stumble at the

PLATE IX.

Vertical Style

Horizontal Style

threshold, not knowing what a section is; the term profile would have been better, for that means a *vertical* section. It may serve to convey an idea of a profile of a hill, if the reader will call to mind the appearance it would present in hazy weather, when nothing but the outline is visible; or, referring to the ground plan in plate IX., let him conceive the hills there represented to be cut away from the dotted line, AB, so as to leave the face of the remaining parts of the hills perpendicular: this face would then present the exact appearance of the profile given in the plate.

By a little attention to what has been said above, I think the student will be able to comprehend the nature of a ground plan of hill features, with its corresponding section, as here shown.

METHODS OF SHADING HILLS, ETC.

The shading of hills may be performed by using a black-lead pencil, with a pen, by washes of Indian ink, or neutral tint, &c.

There are two modes of expressing inclinations of ground with the pen or lead pencil, distinguished as the vertical and horizontal manners. In this country, opinion is divided as to which method is the best for general purposes. The examples given in the plates, hitherto, have all been in the vertical style of shading; adopted in my work, because I think, on the whole, that a beginner would find it easiest both to understand and execute; that it is the quickest for field sketching, and has been the most generally practised.

The *vertical* mode, as already stated, assumes the pen strokes to represent such minute rills as water forms when trickling down the slope of a hill. The *horizontal* manner marks the contours of hills by waving lines, each line continuing on the same *level* while following every undulation of the ground; as, in some hilly parts of this country, sheep paths may be observed, often covering the entire faces of steep declivities, at a few feet apart, and horizontally pursuing their windings.

Mr. Burr, the Professor of Military Surveying at Sandhurst, showed me recently what I think a very ingenious and striking way of conveying a just idea of this style by means of a model in plaster of Paris, representing some hilly ground. He had enclosed his model in a wooden box, which was then filled with water. A scale, divided into quarters of an inch, having been placed upright in the box, the water was allowed to run off through a hole near the bottom, by a quarter of an inch at a time, as indicated by his scale. At every successive fall of the water, he traced lines on the model, indicating the curves shown upon its surface by the successive lowering of the water. When the operation was completed, the surface of his model exhibited a number of lines, all of course perfectly horizontal; closing upon each other where the hills were steep, and diverging again where the slopes became more gentle. A model so prepared is easily represented on paper, and with great accuracy; and I cannot do better than recommend those who are desirous to obtain a thorough knowledge of *ground*, to consider the horizontal method with attention, as it reduces the delineation of hills to something of a fixed principle. In practice, either or both of the styles may be used at the pleasure of the draftsman, or as may be best suited to the nature of the ground he wishes to pourtray. The sketch in plate XI. is a specimen of the contour method.

The vertical style of sketching hills used to be generally practised in the British service; so much so, that I do not think a single officer of the Royal Staff Corps employed the horizontal manner; but of late years the latter has been in favour at our military colleges, and now bids fair entirely to supersede the vertical method. A very able military surveyor, and possessing as much practical experience as any officer in our service, makes the following remarks on the two styles:*—"The features of ground were expressed formerly by curve lines, parallel to the horizon, covering the convex or concave sides. The modern, or, as it is termed for the sake of distinction, the vertical style (written in 1827), is preferable, for several reasons, among which the following may be stated:—

"Roads deviate as little as possible from a hori-

* "Outlines of a System of Surveying," &c. By Major Sir T. L. Livingstone, Surveyor-General of New South Wales.

zontal plane: on a convex or concave surface they cannot continue in such a plane but in curvilinear directions. Roads amongst hills are, therefore, generally of this description; they would, consequently, be parallel to curve lines expressing the ground, and therefore not readily distinguished from them on a field sketch. In the vertical style, the road is parallel to the lines, only when its ascent is direct, which rarely occurs: when the direction is horizontal, each line will be crossed by the road at right-angles. A diagonal direction will indicate an oblique ascent, proportioned to the angle with the lines and that of the direct acclivity.

" Any projection of stratified rocks on the side of a hill may be shown with effect, by strong characteristic touches across the vertical lines; and also all other natural and artificial circumstances, which occur most frequently in planes parallel to the horizon.

" There is another advantage in the vertical direction of the lines, which is, that it becomes the very style of the engraver, who cannot have too close a guide in the delineation of the ground, since that is a subject which admits of no deviation on the part of the copy, whether as to outline or shade; while, as the loose character of the originals has hitherto been an insuperable bar to improvements in this branch of the art, any approximation in style between the draftsman and the engraver is very desirable.

"The most common character of the sides of hills (as seen in profile) being that of a double curve, it is obvious that there is no particular part near the summit, or base, of such a form which could be selected as proper for the commencement of concentric circles, or curves, to represent that as it would appear under a vertical light. The first lines around the summit, and the last at the base, cannot easily be melted into that soft appearance of natural shade which is produced by lines radiating from the summit. The gradual termination of any of these is scarcely perceptible at the summit and the base, while the sensible breadth near the middle denotes the part most inclined to the horizon. By unevenness of termination, the peculiar form of any summit is expressed with softness, or its circularity is shown by the points of many lines without the stiffness of the circular line. Slight features at the base of a hill are also easily connected with it, by continuing the lines.

"More may be expressed with fewer lines, in sketching according to the vertical style. Three or four divergent lines will mark the situation of a hill and the extent of its base; curves at a similar distance would show no connexion amongst other curvilinear lines, representing roads, &c.

"The advantage of the vertical lines is still more apparent in representing ridges of that uniform character, which occur so generally in the Pyrenees and the Alps; the angle at which the lines meet the beds of torrents, expresses the direction and rapidity of their descent. Such are the reasons in favour of the vertical method of drawing the lines."

If the student could procure a good model or two, with plans of them, he would derive great advantage from an attentive comparison of the latter with the former. He might then lay aside the plans, and endeavour to make others for himself from the models, which he could afterwards compare with the other plans. By such a practice, he would speedily attain to great facility in sketching, and the knowledge of ground: after which he might proceed to sketch from nature, which he would find very easy, owing to his previous course with models. Unfortunately, good models and plans of them are not easily procured; the student must, therefore, go at once to the field, and work from nature, as shown in the following section on sketching-ground.*

The most rapid way of expressing hills upon paper, is by shading with Indian ink or neutral tint: for this, two camel-hair brushes are used, one to lay on the tint with, and the other for softening it down. A dexterous hand will, in this manner, speedily dash in the hills of a plan: but a few touches with a pen over the shading, enable an

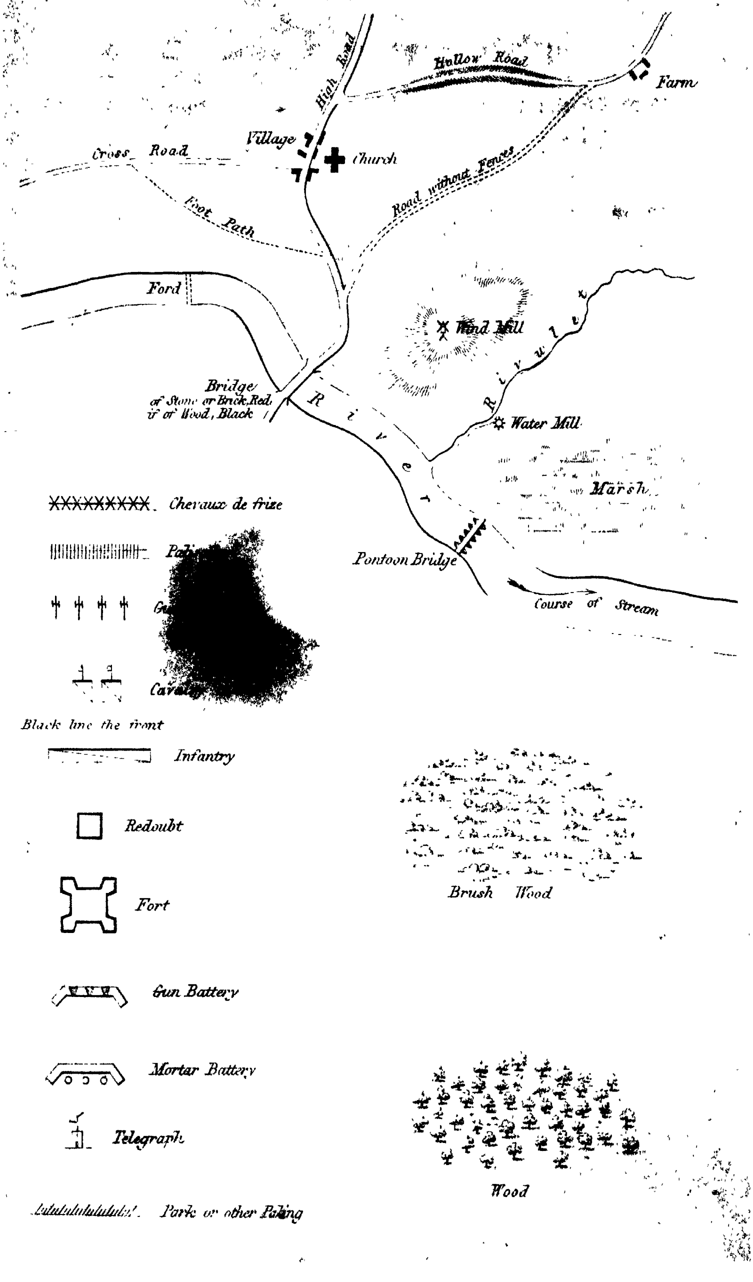
* At the East India Company's Military College very extensive modelling is practised with *wet sand*. This material was proposed for the purpose by Lieutenant Cook, F.R.S., Assistant Professor of Fortification at that Institution: it is found to answer admirably.

artist to give form to the features of ground with less labour than by brush-shading alone. All touches, however, that are introduced with no other object than to produce effect, are very objectionable. If rugged ground is to be pourtrayed, free touches become necessary; but the judicious draftsman will endeavour to suit his style to the nature of the hills he has to express: steep and broken declivities will admit of freedom in the touch, but smooth and gentle slopes must be made to preserve their proper character; and yet a proficient with the brush or pen, will always contrive to throw a certain degree of spirit into his performance, whatever may be the nature of the ground he is representing: but this is the result of much practice, combined with a natural taste for drawing.

I have already said that the rays of light are supposed to fall vertically upon the ground, and that the degree of shade used for expressing hills depends on the greater or less gradations of their declivities; that is, the more the slope of a hill recedes from the horizontal, the darker must be the shade. Now, although I consider this principle as generally the best, yet, in making a finished plan of any mountainous region, I would not confine an artist too rigorously in this respect; for a clever draftsman would then like to throw his mountains into what we term light and shade, which supposes the rays of light to come on the plan from the left upper corner; according to which supposition, one side of a hill becomes brightly illuminated, while its reverse is cast into deep shadow. I have seen some very beautiful specimens of plans executed in this manner, by which a surprising effect was produced. Attempts have been made to have the oblique light system generally adopted, but it is not suited to express tame ground. A kind of compromise therefore subsists; thus, we make the rays of light to fall vertically upon the hills, while all other objects, as rivers, houses, trees, &c., receive it obliquely. This, to be sure, does seem rather absurd; but, where all is conventional, the contradiction is not felt as an inconvenience; and it may be observed that, generally speaking, the object of giving shadow to houses, rivers, &c., is chiefly as a finish, and for effect; although, in the plans of engineers and architects, it is usually attended with utility.

Little need be added with respect to mere plan-drawing: some few additional remarks, which naturally suggest themselves on a consideration of the subject, will be found in some general observations upon sketching in the field (see Section XII.); plan-drawing, in its most limited sense, and field sketching, being so intimately connected, that strictly speaking they can scarcely be separated: besides, I do not think it would be attended with any advantage to the student, were I to enter minutely into the details of plan-drawing. From description alone, I conceive it to be out of the question that any one can form a correct idea of the

Plate 1.



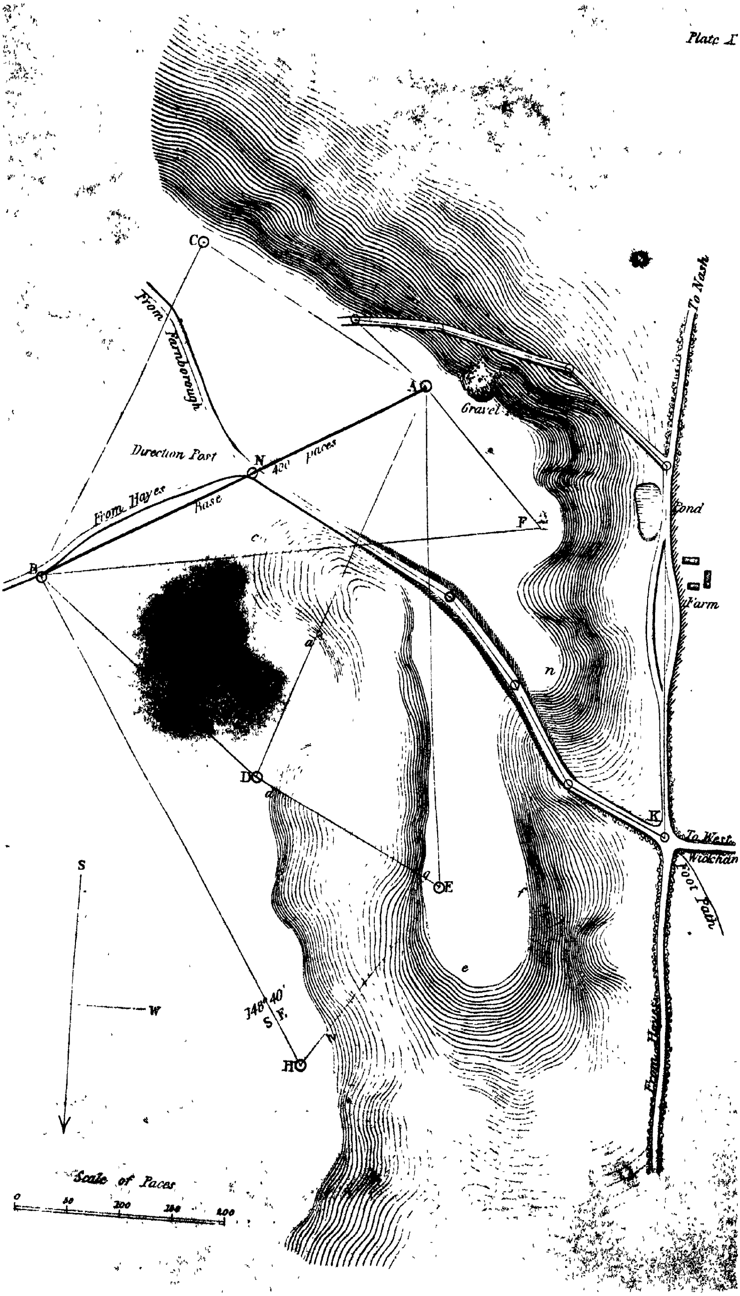
High Road
Hollow Road
Farm
Village
Church
Cross Road
Road without Fences
Foot Path
Ford
Wind Mill
Rivulet
Bridge
of Stone or Brick, Red,
if of Wood, Black
River
Water Mill
Marsh
Cheraux de frize
Pontoon Bridge
Course of Stream
Pal
Ga
Cav
Black line the front
Infantry
Redoubt
Fort
Gun Battery
Mortar Battery
Telegraph
Park or other Paling
Brush Wood
Wood

manner of executing a finished plan; neither do I consider very great skill in the art as imperative on officers in general. All that is really wanted for use in the field may be scratched with a pen. Our engraved maps are none the less useful that the rivers, roads, woods, &c., are colourless. A person seeking to acquire a thorough knowledge of military plan-drawing, must either procure plans to copy, or obtain instruction in the art beyond what a book can furnish; I therefore hold it useless to swell my pages with elaborate details on the subject.

Plans are copied in various ways. The best is by tracing at a glass frame or window; for which purpose the paper intended to receive the copy is pinned to the original. When mounted on paste-board, or other opaque substance, some other mode must be resorted to, as that of dividing the original plan into compartments or squares, by ruling lines upon it lightly with a pencil; similar squares are then formed on the paper, and the copying becomes easy. This latter method is employed for increasing or diminishing the size of the copy, as compared with the original. By using what is called tracing paper, through which the details of a plan are visible, a copy is speedily and very correctly made; and afterwards, if necessary, a tracing may be made from it upon thick paper at a window. There are also other methods, but the above are sufficient.

Plate X. contains the conventional signs in plan-drawing, which are generally employed: instead of multiplying these to an inconvenient extent, it is better to make memoranda on the plans. For instance, signs are sometimes used to denote whether a ford or a marsh be passable for troops; and even to notice whether practicable for infantry, as well as guns and cavalry; but, in my opinion, it is better to say, in language that cannot be mistaken, what description of ford it may be.

Plate I



C
From Farnborough
A
Gravel
Direction Post
N
400 paces
From Hayes
Base
F
B
To Nash
Pond
Farm
n
c
a
D
d
a
E
e
K
To West Wickham
Foot Path
From Hayes
S
W
148° 40'
S F.
H
Scale of Paces
0
50
100
150
200

SECTION X.

ON SKETCHING GROUND.

It is a comparatively easy task to convey to the understanding of a student tolerably just ideas upon almost all the subjects touched upon in the foregoing portion of this work; to describe instruments, the methods of using them in the field, and laying down the work afterwards, is attended with little difficulty; but it seems to me, that the operation of sketching the features of ground is not so easily rendered intelligible by description alone. The measurement of angles and distances has more in it of a mechanical proceeding than the subject I now purpose to glance at.

Perhaps I cannot adopt a better way of showing how it is usually performed, than by going step by step through the whole of a real military sketch, which was recently made. Accordingly, I shall describe minutely the whole proceeding, from beginning to end; apologizing for a little repetition, as, in order to render the sketch complete, I must necessarily go over again the preliminary process, already given in Section III., namely, the laying down of points preparatory to sketching the features of the ground.

We first examined our ground, when it appeared that the line, AB (plate XI.), gave us the best direction for a base, being easily measured; whereas, in most other directions, the furze bushes rendered it impossible to walk in a direct line: AB measured 400 paces of 30 inches. We next planted bandrols at what appeared the most favourable points for enabling us to sketch the features of the ground; these were C, D, and E. At A we set up the compass on its stand, and found that B bore 62° 35′ E. A point was marked on the paper for A, and the ivory protractor adjusted to the east and west lines on our paper. The line, AB, was then made to form an angle of 62° 35′ east of the meridian, and 400 being taken from a scale of equal parts the point, B, was fixed. We then made use of a pocket sextant, and took the following angles while at A, namely:—

BAC	56°	3′
BAD	41	0
BAE	66	37
BAF	106	25

[F being a remarkable tree.]

We then went to B, and took

ABC	37°	30′
ABF	19	41
ABD	65	30

The points, C, F, and D, having been thus determined by intersections, we went to D, and took an angle, ADE, of 96°, which fixed E.

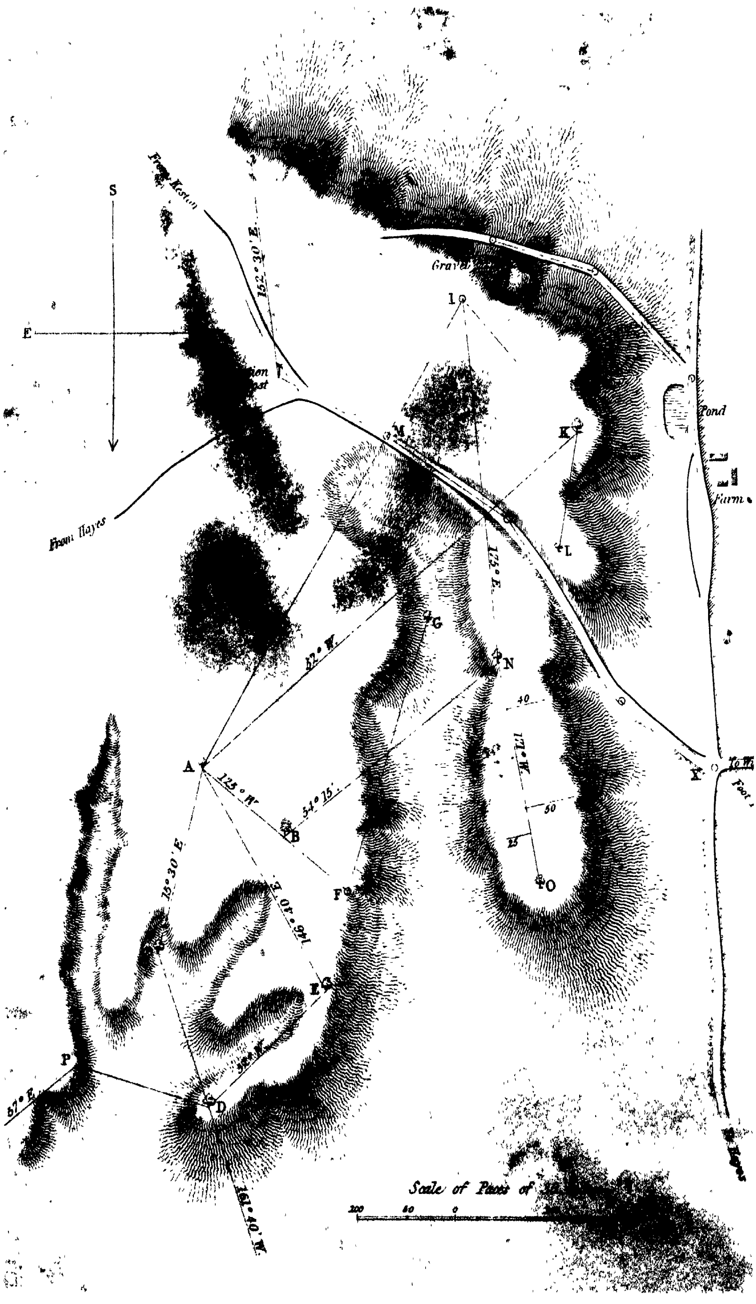
Having now sufficient points established, we began to sketch the ground. Being at D, we commenced by observing that towards E it began to fall at 20 paces — this point was marked as *d*. We then returned to D, and walked direct upon A, until at 120 paces we came to the declivity at *a*: the curve from *d* to *a* was then marked on the paper, and a little shading performed. We then noticed how the ravine went with reference to C, and were enabled to sketch in as far as *c*. We then turned back, and passed D, going in the direction of H, until we came to a point that we saw would be useful to us—to determine which we set up our compass, and took a bearing to B of 148° 40′ E. Also one to E, of 36° 5′ W. To find our place then at H, we had only to adjust the protractor at B and at E, and protract the opposite bearings (see page 17); accordingly, we laid off from B, 148° 40′ W.; and from E, 36° 5′ E.: the intersection of these lines fixed H. Again for the sketching — looking towards E, the declivity began at about 30 paces from H, at *h*—the ground *h* to *d* was then sketched in.

E was our next point — the distance to *e* was found to be 50 paces, in continuation of the line A E. To fix *f*, we paced in a direction at right angles to the line, E A, 80 paces, and to *g*, being 15 paces, the curve, *f e g*, was swept, and the ground shaded. We then noticed that the crest of the ravine continued for 100 paces nearly in the direction of A, after which it inclined somewhat to the left, until at length the curve united with that portion of the sketch which was first put in. We then went to the point *n*, found our place by taking bearings to E and A, and sketched the ground there, uniting it with that at *f*.

Our next move was to the tree at F, round which we sketched the ground, uniting it with what had been already drawn in the direction of *n*. The sketching was then continued towards A.

It must be needless to say more about sketching the ground, so far as relates to this little plan—perhaps I have already been but too minute.

The roads were thus put in:—the distance from B to N having been ascertained, the compass was set up at N, from whence bearings were taken towards K (Section II.), and from thence past the farm, until we ascended a road that brought us to the summit of the high ground near A, upon which station we closed with tolerable accuracy. It would have been desirable for us to have got sight of one or two of our primary stations during the course of our progress by the road; but almost immediately on leaving N, we entered a hollow way, which hid every thing from our view, until we reached the bottom of the hill at K, from whence, could we have seen E and F, we should have taken bearings to those stations, in order to make sure of our place at K, and as a check on the work; but E was hidden by the brow of the hill, and F by trees, thickly strewed over the face of the ground in that part.



S
E
152° 30' E.
From Hayes
Gravel
I
Pond
K
Farm
M
L
173° E.
G
52° W.
N
40
171° W.
A
125° W.
54° 15'
X
50
B
25
15° 30' E
F
O
146° 40' E.
P
67° E.
D
161° 40' W.
Scale of Paces of
200
50
0

The student will perceive that, in the sketching above detailed, we could not possibly have been much out at any time. The primary points, together with imaginary lines connecting them, enabled us to refer the contours of the ground to what was laid down with certainty; and all by a process so simple and easy, that no one present could have failed to be fully master of it.

I shall now show the manner in which a military sketch was rapidly executed, without measuring a base line or using other marks than some trees and bushes as they existed on the ground. The instrument used for taking bearings was a prismatic compass, held in the hand, and each individual was provided with a sketching block ruled with parallel lines, an ivory protractor, and a black-lead pencil.

A tree, A (plate XII.), was selected as the point at which to commence operations: from whence we could distinguish a little knoll, I, a large tree, K, and the trees, C and B. No other objects visible from A seemed likely to be of service to us in sketching the ground, or putting in the roads. Bearings to those objects were then taken, viz., to I, 34° W.; to K, 52° W.; C, 15° 30′ E.; and B, 125° W.; the distances of the trees, B and C, were then paced, and found to be 98 and 156 paces respectively, which determined their positions. When pacing between the trees at A and C, we noticed at what point the ground began to fall, and with the aid of the trees, C and B, we were enabled to sketch the features of the ground in their vicinity; having done which, a bearing was taken to a small bush, on the summit of the hill at D, 161° 40′ W., and the distance, CD, was found to be 147 paces. The ground about D was then sketched, and connected with that already done. The bearing of a bush, P, was next taken, and from thence a bearing to a distant object, of 57° E, enabled us to put in the ground as it appears in the sketch. Returning to D, the direction of a bush at E was ascertained, and its distance from D found to be 150 paces. A bearing then taken from E upon A, served to check the work thus far.

The point, F, was taken in line with the trees, A and B, 80 paces from the latter; the bearing of a tree, G, being then taken was found to be 17° W. The ground was sketched towards G, and the distance determined by pacing. Our next move was to a tree at N, from whence we found both I and B were visible; the bearing of the former was 175° E., that of B, 54° 15′ E.: we had then only to protract 175° W. from I, and 54° 15′ W. from B, to determine the point, N (see Section IV.). The breadth of the summit of the hill, NO, was taken by means of offsets, as marked on the sketch.

To put in the roads was our next object. We found the point, M, by pacing from A upon I, and then took bearings down the road to the point, X, and from thence by the farm and pond, up the hill, past the gravel-pit and the knoll, I.

After so very minute a description as the above, it must be unnecessary to detail how the rest of the sketch was obtained; the student can readily make it out for himself with a little attention.

Having given this second example, I ought to observe that, when our object is to obtain a good military sketch of a few square miles of country, the method of triangulation from a base line is much to be preferred; but for minor sketches, and when an officer is unprovided with the necessary assistance for setting up marks; in short, when he is alone, and must make use of objects for his station-points as he finds them on the ground, the method last described will prove very convenient.

I now proceed to give a few general hints to the military surveyor. He must have a triangulation, if possible, to establish certain landmarks, as the primary stations may be termed; after which the filling in of an extensive survey is done by laying down the roads, rivers, boundaries of woods, &c., so as to form a skeleton preparatory to sketching the ground. This effected, the surveyor then examines the ridges, observes the sweep of a hill, or the direction of a valley, and refers all to the points already laid down on his paper. He takes no measurements, save by the eye, but finds his place by interpolation (Section IV.), as occasion may require. He commences at the highest situations, and, working his way downwards, is careful only to sketch the features he actually goes upon; as nothing can be more fallacious than to suppose the nature and slopes of any portion of ground not immediately under the eye. Every feature must be traversed if he wish to ensure accuracy, and I recommend him to touch the hills in lightly at first, until he is quite sure of being correct; occasionally, also, he should hold his sketch so as to correspond with the ground, which is easily done by means of the fixed points, and observe whether the features on the paper agree with those of the country before him. He must be sure to take the bearings of all remarkable objects while at any situation that has been determined, as a little foresight may save the trouble of a return to it.

There is still a consideration that must claim the notice of the student, and which he must exercise his judgment upon in the field; namely, the degree of detail which his *scale* will admit of in sketching hills: thus a number of minor features which a large scale, as 20 inches to a mile, will enable him to express, must necessarily be omitted when the scale is only four or six inches to a mile. Indeed, this consideration should be attended to in all kinds of drawing, otherwise a mere mass of confusion must be the consequence. Again, if the scale be small, some objects require to be drawn larger than the truth; roads, rivers, houses, and indeed almost everything introduced, must partake of this exaggeration, except hills; these can never be increased or diminished beyond the truth, but their minor features may be expressed or omitted, according to the scale used.

Enough has probably now been said on the subject. Once master of the principles on which sketching is conducted, the student's own observations will speedily enable him to discover many little modes of diminishing his labour, and of securing correctness.

I would, however, impress on him that it is necessary he should practise himself in judging distances by the eye; as, when once he can depend on its measurements, he will be able to spare himself much fatigue, consequent on determining them by pacing. Let me not, however, be misunderstood, and have it imagined that I recommend sketching by the eye alone, and without any aid from instruments. Eye sketches are very well when an instrument happens not to be at hand; but it is most desirable, when possible, always to fix a few points in any sketch, however trifling, with an instrument. In this way even time will be saved; and as to correctness, little dependence can be placed on an organ, which, although capable of being brought to great perfection in estimating distances, is ever but a poor instrument for measuring angles.

SECTION XI.

GENERAL REMARKS ON SURVEYING, PLAN-DRAWING, AND SKETCHING.

Military Topography, notwithstanding the boasted improvements made in it abroad — to say nothing of some few attempts to advance the art amongst ourselves — is, so far as I may pretend to give an opinion, nearly where it stood thirty or forty years ago. And the same remark holds good with respect to surveying generally. This, however, is by no means surprising. Surveying, in all its branches, being an exceedingly simple process — requiring, it is true, for great trigonometrical operations that the surveyors should be men of science, in order that certain measurements may be made with the utmost possible accuracy: yet the principles of surveying are easy of acquirement; and their application, under ordinary circumstances, requires little beyond good instruments, and great exactness in the use of them.

I really think that few persons can rise from a study of the "Account of the Trigonometrical Survey," without entertaining an impression that geometrical and trigonometrical operations, as applied to measurement on the earth's surface, were on that occasion carried very nearly to perfection.

So far, then, as horizontal measurements are required, whether for the purpose of mapping countries, or of determining the length of an arc of a meridian, it does not seem that anything remains to be desired.

Again, the height and exact slopes of hills, as also the depression of valleys, to suit the purposes of the military or civil engineer, can be obtained with the utmost accuracy, by means of levelling and trigonometrical operations. So that in every accessible part of a country, the most perfect knowledge of its surface, whether flat or mountainous, may be obtained: and, having plans and sections accurately drawn to a scale, we can at any time measure distances upon paper. But although we can measure *horizontal* distances over every part of a map or plan, yet *vertical* measurements, as those of heights and depths — shown on paper by *sections* — can only be made upon the precise lines along which such sections have been carefully taken; and if other vertical measurements are wanted, our ground plans can avail us nothing: we must proceed to the ground, and ascertain them by actual operations.

Herein lies the imperfection of plans; and the attention of scientific men has long been directed towards the discovery of a method of drawing ground plans, from which sectional measurements may be made. Hitherto their efforts have been attended only with partial success — that is to say, by means of very great accuracy in taking measurements over the surface of a hill—similar indeed to what would be requisite for sections—a knowledge of its form being obtained, symbols are used to designate a certain degree of perpendicular elevation, together with the angle at which the hill slopes at each gradation. Thus, in France, military engineers run a succession of horizontal lines round their hills at every ten mètres of difference of level, by which they obtain two sides with their included angle of a right-angled triangle, namely, the perpendicular height of ten mètres, and the *base* of the slope, for that distance of perpendicular height, with the included right angle; from which data the value of the slopes at every gradation can be obtained.

In some of the continental countries a system of shading is used according to a scale—different degrees of shade representing the angles at which a hill slopes. This is the principle of Major Lehman's method, and prevails among the Germans.

A few years ago, the late Sir J. C. Smyth, of the Royal Engineers, published a little work, to recommend a modification of the *normal* system, as set forth by Colonel Van Gorkum, of the Netherlands' army, for adoption in our service. But I very much doubt whether any of these systems can be rendered available for general topographical purposes.

The system of tracing contour lines, upon a plan of any portion of ground, as introduced by the French officers of engineers, is now gaining ground amongst those in the British service, and is practised in the trigonometrical survey under the direction of Colonel Colby: "these lines being traced at short, *known, and generally equal vertical distances* over the ground, afford ample data for the construction of sections in any required directions, and even for a model of the features of the ground."* The method of tracing the contour lines will be found under the head *Levelling* (Section XVII.): the process is necessarily slow; but there can be no question, that a plan of any portion of ground may thereby be obtained with mathematical accuracy. A moment's consideration will, however, convince any one that it is wholly unsuited to the ordinary purposes of the topographical draftsman, who has often a considerable extent of country to delineate in a very short time; and for objects, moreover, which do not require the ground to be sketched with extreme precision.

Most assuredly it is a great desideratum, to be able, by the inspection of a map or plan, to determine the elevation of the hills: and the person who may discover a truly practical system, that shall be at the same time general in its application, will confer an immense benefit on the art of plan-drawing. At the same time, however, I am

* "Outline of the Method of conducting a Trigonometrical Survey," &c., by Capt. Frome, Royal Engineers.

desirous to guard my readers against any erroneous notions on this head. Such a discovery, though unquestionably of great importance, as at once rendering a plan perfect, would not, in my humble opinion, add so much as might be imagined to its utility for the general purposes of war. It appears to me that, looking alone to these, the height of hills, as compared with others near them, is the principal consideration with a General. Next to which, in point of importance, comes the nature of the slopes; whether steep and rugged, or gentle and smooth; how far practicable for his troops of all arms to operate upon. But whether the summit of a hill, or of any portion of ground be a certain number of feet, more or less, higher than the sea, or than the level of a river flowing near it, can be of no moment whatever.

A practice formerly prevailed, and one that I think might be revived with advantage, by which the comparative heights of hills were at once seen on a plan; I allude to their designation by numbers. This practice fell into disuse owing to the pretension it had, of not only serving to distinguish comparative, but likewise to show positive, elevation. For this latter purpose, a perpendicular height of 36 feet was termed a *command*, and the figures 1, 2, 3, &c., denoted so many of these commands. Like most of the attempts made to show positive vertical height upon a ground plan, this method by commands proved a failure, from the impossibility of obtaining the data on which to lay them down, without a tedious levelling process. But I think that we did wrong to reject the whole of the system, because one part of it was found defective; and in this opinion I would recommend a modification of it: thus, let the figures be reversed, and instead of giving the highest number to the loftiest ground in a plan, mark that as No. 1, the next in height as No. 2, and so on; giving, of course, the same number to ground of equal elevation. Our plan-drawers will here be ready to exclaim, "Oh, but this is all shown by our degrees of shade, and there is no necessity for disfiguring our plans by numbering the features of ground in this manner." To which I reply by an expression of doubt upon that head; seeing that all men who pretend to be draftsmen are not equally competent to produce plans that are to be depended on: what is termed a good knowledge of ground is not within the reach of every one, any more than is the *coup-d'œil militaire.* But, although I may often have my doubts with respect to the correctness of the shading, I should be disposed to give some credit to the figures; for any one accustomed to sketching can always see whether a feature is higher or lower than another, when the difference is of any consequence; and on occasions where he may be unable to distinguish the higher ground, from the difference of level being slight, the same number may be used for both: besides, a plan so marked would be much easier read, particularly by persons not intimately conversant with the rules of plan-drawing.

The uncertain application of conventional rules, such as those which regulate plan-drawing, does a vast deal of mischief; and there is great reason to regret that such diversity of style in drawing should be tolerated in this country; but I fear there is no remedy for the evil. Could we by any possibility be tied down to one approved style of delineating ground, such a measure would go far towards establishing conformity in the depth and gradation of shade among draftsmen. The ingenious author of "A Treatise on Practical Surveying and Topographical Plan-drawing," Mr. Burr, has bestowed much care on the subject of shading plans, but few will be found to attend to his instructions. Yet, while the variety of styles complained of is suffered to exist, there can be no uniformity in this respect; the result of which is that, supposing two persons to have the same range of ground to draw, one of them will use shades twice as dark as the other. Thus, when an extensive district is to be sketched, upon which several individuals are required to be employed, it becomes impossible to unite their sketches, so as to form a complete whole; nor can it be determined whose portion contains the most elevated ground.

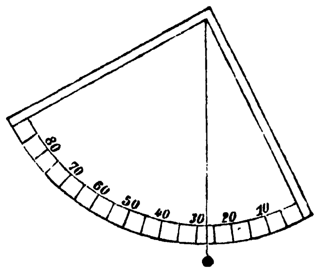
In the early part of this work, I have mentioned that a portion of the French territory was sketched by the officers of the Royal Staff Corps. On that occasion the several sketches united very well, with one or two exceptions; as almost all the individuals employed were educated at the Royal Military College, and had, as I may say, a common scale of shades in their minds, and they had therefore only to agree upon the *style* to be used.

I may here remark that, almost universally, the shades used by draftsmen are too dark; they would do well to pay more attention to truth in their plans, and less to effect.

Previously to taking leave of the subject touched on in these few observations, I may observe that the most useful sketches are those which are rapidly made of country, in advance of an Army in the field, termed reconnoitring ones; which is, in fact, exploring it. Under this head come, also, the necessary reports and sketches of roads, forms of which will be found further on. It may be some consolation for officers who have not had a regular military education at any of our colleges, to be told that this, the most important duty of a staff officer in the Quarter-Master General's department, does not demand by any means a perfect knowledge of military surveying. General intelligence, knowledge of languages, boldness, perseverance, a quick eye, and a prismatic compass, are his chief requisites: these have laid the foundation of many a one's military fortune.

I shall close this section with a few valuable hints on sketching, by Capt. Frome, Royal Engineers:*—

"The inclination of such slopes as are of peculiar moment should be measured with a 'clinometer,' and the angles written either on the slopes themselves or as references. This little instrument can be made by cutting a small quadrant out of pasteboard, and roughly graduating the arc. A small shot, suspended by a piece of silk, forms the plummet; and, independently of its use in measuring vertical angles, it is of great assistance in tracing level lines in sketching the contours.



The instrument sold under this name is made with a spirit level; but the substitute, as described above, answers the purpose equally well; and, moreover, from its being made merely of pasteboard, fits into the pocket of the sketching portfolio.

"The slopes most necessary to note on a military sketch, are those which relate to the facilities of ascent for cavalry and infantry. According to the 'Aide Mémoire,' a slope of about

60°, or of 4 to 7 is inaccessible for infantry.
45°, or of 1 to 1, difficult.

* "Outline of the Method of conducting a Trigonometrical Survey for the Formation of Topographical Plans."

If 30°, about 7 to 4, inaccessible for cavalry.
15°, —— 4 to 1, inaccessible for wheel carriages.
5°, ——12 to 1, easy for carriages.

"The leading features of ground are the summit ridges of hills (sometimes termed the water-shed lines), and the lowest parts of the valleys, down which the rain finds its way to the nearest rivers and pools, called water-course lines. These two directing lines, if traced with care, will alone give some idea of the surface of the country, and assist materially in sketching the hills; particularly if drawn on the horizontal system, as the *contour lines always cut the ridges, and all lines of greatest inclination, at right angles.* It is a very common error, on first beginning to sketch ground, to regard hills as isolated features, as they often appear to the eye; observation, and a knowledge of the outlines of geology, inevitably produce more enlarged ideas respecting their combinations; and analogy soon points out where to expect the existence of fords, springs, defiles, and other important features incidental to peculiar formations; and appearances that at one time presented nothing but confusion and irregularity, will, as the eye becomes more experienced, be recognised as the results of general and known laws of nature.

"The representation of the outline of hills, and their relative command, is also materially assisted in a topographical plan, and *more particularly in a military reconnaissance*, by a few outline sketches taken from spots where the best general views can be obtained. A series of these topographical sketches, running along the length of a range of hills, and a few taken perpendicular to this direction, supply in some degree the place of longitudinal and transverse sections; and give, in addition to the information communicated by a mere section, a general idea of the nature of the surrounding country.

"A good judgment of distances is indispensable in sketching ground, even in filling up the interior of a survey; and more particularly in a reconnaissance, when there has not been either time or means for accurate measurement or triangulation. Practising for a few days will enable an officer to estimate, with tolerable accuracy, the length and average quickness of his ordinary pace, as also that of his horse—as on a rapid reconnaissance he must necessarily be mounted—and the habit of guessing distances, which can afterwards be verified, will tend to correct his eye. A micrometrical scale* in the eyepiece of his field telescope, with a corresponding table of distances, is also a very useful auxiliary; and the gradual blending of colours, the angles subtended at different distances by objects of known dimensions, such as the height of a door, or a man, and the well-known rate at which sound has been ascertained to travel,† will also materially assist him. According

* See description of Dr. Brewster's micrometrical telescope, in vol. ii. of "Dr. Pearson's Practical Astronomy."

† "About 1140 feet in one second. A light breeze will increase

to the 'Aide Mémoire,' the windows of a large house can generally be counted at the distance of three miles; men and horses can just be perceived as points at about 2200 yards; a horse is clearly distinguished at 1300 yards; the movements of a man at 850 yards; a man's head clearly visible at 400 yards, and partially so between that distance and 700 yards."

or diminish this quantity fifteen or twenty feet in a second, according as its direction is to or from the observer; in a gale a considerable difference will arise from the effects of the wind. A common watch generally beats five times in one second. (See 'Philosophical Transactions,' 1823.) The number of pulsations of a man in health is about seventy-five per minute: either of these expedients will serve as a sort of substitute for a second's watch. The velocity of sound is affected by the state of the atmosphere indicated by the thermometer, hygrometer, and barometer; according to Mr. Goldingham 1-10th of an inch rise in the barometer diminishes the velocity about nine feet per second.

SECTION XII.

OF THE POCKET SEXTANT.—ITS ADJUSTMENTS—USE IN SURVEYING, MEASURING HEIGHTS AND DISTANCES, ETC.

WITH a view of not distracting the attention of the student, little or no mention has been made thus far of any surveying instruments, save such as were absolutely necessary in order to illustrate our descriptions of the various methods of proceeding: but although we have hitherto confined ourselves to the theodolite and compass, it is not to be inferred that we reject all others. The pocket sextant and the reflecting semicircle, are both applicable to the purposes of military men, and may be advantageously used on many occasions instead of a theodolite or compass. We shall now proceed to give a particular description of the sextant, and to explain the several uses to which this beautiful instrument may be applied.

The pocket sextant combines numerous valuable properties; it measures an angle to one minute of a degree, requires no support but the hand, may be used on horseback, maintains its adjustment long, and is easily re-adjusted when put out of order. It will determine the latitude by a meridian altitude to one minute, and an approximation may even be made with it to the longitude, by means of lunar

observations. Further, it is very portable, forming when shut up a circular box under 3 inches in diameter, and only $1\frac{1}{2}$ inch deep.

The figure given in plate XIII. represents the instrument screwed to its box, for convenience of holding in the hand, and with the telescope drawn out. A is the index arm, having a vernier adjusted to the graduated arc, B, which latter is numbered to 140°, but the sextant will not measure an angle greater than about 120°. The index is moved by the milled head, C, acting upon a rack and pinion in the interior. Two mirrors are placed inside; the large one, or index mirror, is fixed to and moves with the index; the other, called the horizon-glass, is only half silvered. The proper adjustment of the instrument depends on these glasses being parallel, when the index is at zero; while they are, at the same time, perpendicular to what is termed the plane of the instrument, represented by its upper surface or face. To observe whether the instrument is in perfect adjustment, remove the telescope by pulling it out, and supply its place with a slide for the purpose, in which is a small hole to look through; then place the index accurately at zero, and direct the instrument, holding it horizontally, towards the sharp angle of a building not less than half a mile distant, applying the eye so as to see both through the hole in the slide and also through the unsilvered part of the horizon-glass; the same object ought then to be so reflected from the index-mirror to the silvered part of the horizon-glass, as to seem but one with the object seen direct: if such be not the case, a correction becomes necessary, which is thus performed:—D is a key, removeable at pleasure, that fits two key-holes, the one at *a*, the other at *b*. Apply this key at *a*, and gently turn until the reflected object, and the one seen direct, seem but as one. The glasses are then parallel.

The next point is to examine whether the horizon-glass is perpendicular to the plane of the instrument. For this purpose hold the sextant horizontally, and look at the distant horizon; then, if any adjustment is wanted, two horizons will appear, and the reflected one will be higher or lower than the one seen direct: should this be the case, apply the key at *b*, so as to bring the two horizons together. It must be observed that the large or index-mirror, being correct by construction, it can want no alteration.

By looking at the sun, we can always satisfy ourselves with respect to the adjustments; the telescope has a dark glass at the eye end, and with this on we have only to place the index at zero, and, using the telescope, to look at the sun; when, provided the instrument is in exact adjustment, one perfect orb only will be seen. If the reflected image projects beyond the other, then correction is necessary. The full moon will answer as well as the sun for this purpose, but the dark glass at the eye end of the telescope must then be removed. The instrument is provided with two other dark glasses, which sink out of the way by raising two little levers at *f*.

It has been mentioned above that, for trying the adjustment of the sextant, an object must be half a mile off; this is on account of what is called the parallax of the instrument, occasioned by the necessity of placing the eye of the observer on one side of the index-mirror. Could we look from the middle of it, there would be no parallax; which is the angle subtended by the point of vision and centre of the index-glass, when observing any near object: consequently, as the distance of an object is increased, this angle diminishes, and at length becomes as nothing when compared with it. Half a mile is considered sufficient for all error to vanish, but at half that distance it is scarcely perceptible.

To take an angle, the observer looks either through the telescope or hole in the slide (having previously raised the levers of the dark glasses at *f*), at the *left* hand object, holding the sextant horizontally in his left hand; with his right he turns the milled head, C, until the other object, reflected from the index-glass, appears upon the silvered part of the horizon-glass; exactly covering or agreeing with the left hand object, seen direct through the unsilvered portion of the horizon-glass: the angle is then obtained by the vernier to one minute. Should circumstances render it desirable for the observer to look at the right hand object, he has only to hold the instrument bottom upwards.

If the required angle be a vertical one, the sextant is held in a vertical position by the right hand, while the left turns the milled head, C, until the object is brought down to the horizon.

When the altitude of a celestial body is taken at sea, it is brought down, as the term is, to the natural horizon, and the measure of the angle, or height of the object, is read off upon the graduated arc; but on land the natural horizon can seldom be used, on account of its irregularity: recourse is then had to what is called an artificial horizon, such as a vessel containing water, mercury, or other fluid. The observer then places himself in a situation to see the reflected image of the sun or other body in the fluid; he has only then to bring down the image, as reflected from the index-glass, until it reaches its reflection in the fluid: the altitude will then be *half* the number of degrees indicated by the graduated arc, subject to certain corrections, not necessary to be explained here. [*See Artificial Horizon.*]

The chief, and indeed only objection to the sextant, as a surveying instrument, arises from the angles taken with it not being always, like those measured by the theodolite and compass, *horizontal* ones. If the theodolite be set truly level, we can take angles all round upon its circle, no matter whether one object be high and another low, and these angles will be what are termed horizontal angles; so that, were we to take angles from object to object and complete the circle, the sum of all those angles ought to be 360 degrees, or the measure of a circle. But if the same angles were to be measured by a reflecting instrument, they would not produce precisely 360 degrees, unless taken upon a perfectly level plane; owing to this circumstance, that to take an angle by the sextant, the two objects having to be brought into contact, namely, the reflected one and that seen direct, it is necessary for the observer to hold his instrument, not strictly horizontal, but in the plane of the two objects, or in such a position as will enable him to form the contact; and therefore, if one point is elevated very much above the other, the sextant must be held at a corresponding inclination with the horizon. Angles so taken require a reduction, as it is termed, to horizontal ones; that is, to what those angles would have been, had the points subtending them been on a level with the eye of the observer, which is what is understood by the term horizontal. But as we seldom use the sextant to lay down points for a trigonometrical survey of importance, it rarely occurs that the reduction is required; indeed, to effect it with accuracy is attended with considerable difficulty, as the angles of elevation and depression must be known—a matter of no easy attainment with the sextant. It is better to avoid, if possible, the necessity of making any reductions, by selecting stations neither much elevated nor depressed; and three or four degrees either way can never affect an angle, so as to be of much consequence in military sketching. By a little management, too, a correct eye will enable us to select some spot directly under an elevated object, and at the same time nearly horizontal; such mark may then be taken instead of the object itself: or we may take the angle between each of the objects we are observing, and some other point situated far to the right of them, and the difference will be an approximation to the angle sought. In short, a person habituated to the use of the sextant will generally be prepared with some contrivance, to obviate the necessity of having recourse to the reduction of his angles; which is performed, when requisite, by a calculation in spherical trigonometry, the formula for which will be given in another place.

An addition has lately been made to the pocket box sextant, for the purpose of taking altitudes and depressions: it consists of two small spirit-levels, fixed at the back of the horizon-glass, at right-angles to each other; so that, standing before the object, you look perpendicularly down through the plain sight, and moving the index, bring the image of the object to appear with the levels, which must have their air-bubbles in the centre of their tubes. The reading of the instrument will then show the supplement of the zenith distance, and its complement to 90° will be the angle required; elevated, if more than 90°, and depressed, if less than 90°. A moment's consideration will show that a practised hand is here necessary to catch the bubbles of such minute spirit-levels at the happy instant. This addition has the disadvantage of increasing somewhat the depth of the box, rather an objection in the eyes of military men. And after all, allowing that an approximation may be made by it towards determining an elevation or depression, when the object is very near, I feel certain that with distant ones, which necessarily subtend low angles, the result can never be depended on.

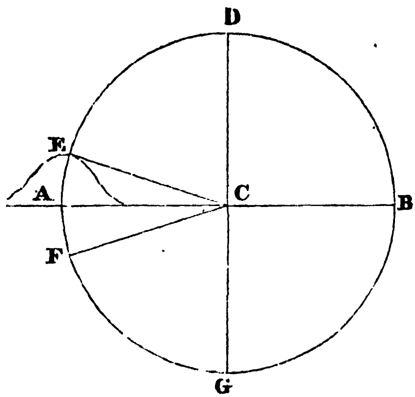
I may just notice here a contrivance for enabling the observer to read large angles with the box sextant—namely, by placing a second index-glass below the other, and at right-angles to it; and having the arc doubly graduated, observations are then taken by looking through a different hole, placed opposite the usual one.

For military purposes, I object to this arrangement; as it reduces the index-glasses to half the original size, and therefore injures the instrument for distant observations.

In order to render this chapter on the sextant as useful as possible, I shall take the liberty of extracting from Mr. Burr's "Practical Treatise on Surveying and Topographical Plan-drawing," a little contrivance, that military men may chance to find of use.

"It has been said in the preceding pages, that reflecting instruments require an artificial horizon to take altitudes; but we cannot use them for small altitudes, because the rim of the vessel, containing the reflecting fluid, renders it impossible, nor can we take depressions by such means: yet, as a military man may have occasion for such observations, and not possess an instrument provided with a vertical arc and level, we shall show how this may be done nearly, that is to say, within two or three minutes, by a reflecting instrument. Place three strong stakes across, like the triangle used for hanging a kettle, upon the ground, binding them firmly at the junction; across two of the legs tie a fine thread tightly, and place underneath any vessel containing a fluid, as mercury or water. Now, it is plain, that when we look from above, so as to bring the thread and its reflected image into exact coincidence, our eye will be in a vertical plane; therefore, by resting upon the stakes, and bringing the reflected image of a distant object into exact contact with the thread, we shall measure the supplement of the zenith distance; and if that is less than 90°, its complement will be the depression; but if above 90°, the surplus will be the elevation. This apparatus can be made any where; and we insert this expedient, in order to show that, with apparently slender means, we may always do something."

I have found this simple expedient to answer very well for an approximation to the height of hills, buildings, &c., and shall add a diagram, which will assist my readers to understand it.

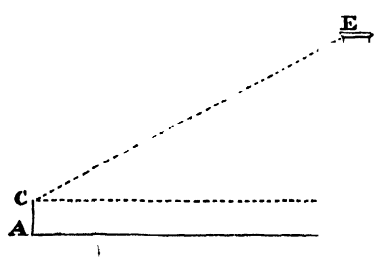


Let C represent the situation of the observer's eye, A B the horizon, and E the top of a hill. E D is then the zenith distance. By the method above given, we measure the angle, E C G, which is, of course, the supplement of the zenith distance, E D; and, consequently, if we deduct 90°, or the angle, ACG, measured by the arc, AG—the angle, ACE, is left, namely, the elevation of E above the horizon. Again, for the depression—suppose our object is to obtain the depression of F—we measure the angle, F C G, the complement of which, or its difference from 90°, gives the angle, A C F, which is the depression of F.

The height and distance of objects, as walls or buildings, whether accessible or otherwise, may be obtained in a very simple and expeditious manner with the sextant, by means of the table of tangents in the next page.

Multiplier.	Angle.	Angle.	Divisor.
1 . .	45° 0′ . .	45° 0′ . .	1
2 . .	63 26 . .	26 34 . .	2
3 . .	71 34 . .	18 26 . .	3
4 . .	75 58 . .	14 2 . .	4
5 . .	78 41 . .	11 19 . .	5
6 . .	80 32 . .	9 28 . .	6
8 . .	82 52 . .	7 8 . .	8
10 . .	84 17 . .	5 43 . .	10

Make a mark upon the object, if accessible, equal to the height of your eye from the ground. Set the index to one of the angles in the table, and retire on *level* ground, until the top is brought by the glasses to coincide with the mark; then, if the angle be greater than 45°, multiply the distance by the corresponding figure to the angle in the table; if it be less, divide; and the product, or quotient, will be the height of the object above the mark. Thus, let E B be a wall, whose height we want to know; and 26° 34′ the angle selected. Make a mark at D equal to the height of the eye; then step back from the wall, until the top at E is brought down by the glasses to coincide with the mark:

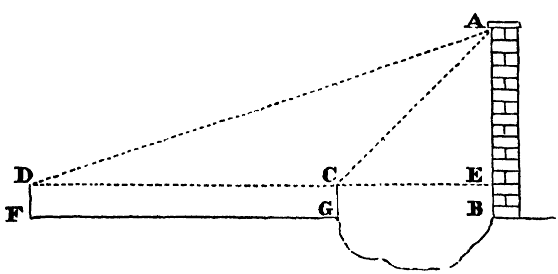


measure the distance, AB, namely, from your station to the wall, and divide that distance by 2, the figure corresponding to 26° 34′, this will give the height, DE, to which BD must be added.

The *parallax* of the instrument has been already mentioned and explained: it exerts an influence on measurements of this kind, from the object being near. To correct it, we have only to ascertain its amount, by placing the index at zero, and looking through the instrument at the top of the wall; when, if influenced by parallax, it will appear as a broken line; but by moving the index a little way on the *arc* of *excess*, or to the left of zero, the broken line will reunite, and the adjustment be effected. When any quantity is taken thus on the arc of excess, the amount must be deducted, when setting the instrument to any of the tabular angles.

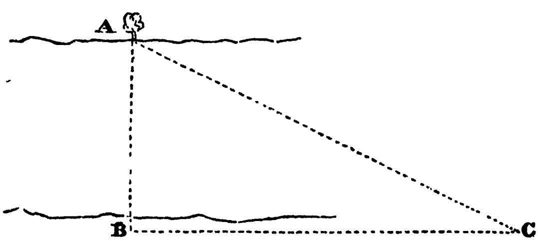
When the object is inaccessible, set the index to the greatest of the divisor angles in the table, that the least distance from the object will admit of, and advance or recede till the top of it is brought down by the sextant to a level with the eye: at this place, set up a staff, equal to the height of the eye. Then set the index to one of the lesser angles, and retire in a line from the object, till the top is brought to coincide with the staff set up to indicate the height of the eye; place a mark here, and measure the distance between the two marks; this, divided by the difference of the figures opposite the angles used, will give the height of the object above the height of the eye, or mark. *For the distance,* multiply the height of the object by the numbers against either of the angles made use of, and the product will be the distance of the object from the place where such angle was used.

The above will be understood better by means of a diagram. Let AB be a wall, not to be approached nearer than C; and that we find, upon trial, that this distance admits of our using the angle 45°: assume a point E on the wall, as the height of the eye; then the index being set to 45°, fix yourself so that the glasses shall bring the top, A, to coincide with E. At this point, place a staff, C G, equal to the height of the eye. Now select any one of the lesser angles from the tables —



18° 26′ for instance, and retire until the point, A, agrees with the top of the staff, C G, which occurs at F. Place a mark at F, and measure the distance from F to G; which, divided by 2, the difference of the numbers opposite to the angles used, will give A E: to which add B E = C G, the height of the eye, and the total height, A B, is obtained. Then, for the distance: the height, A E, multiplied by 3, its corresponding figure, will give the length, D E: and A E, multiplied by 1, will, in like manner, give G B = A E in this instance.

Horizontal distances, as well as heights, may be ascertained by means of the table, where the ground is level. Thus, suppose we wish to measure the breadth of a river, denoted by the line A B: set the index to an angle of the table, place a mark at B, and proceed in a direction, C, at right-angles to A B, until the glasses of the instrument show A and B in contact: then will the distance, A B, be a product or quotient of the base, B C, according

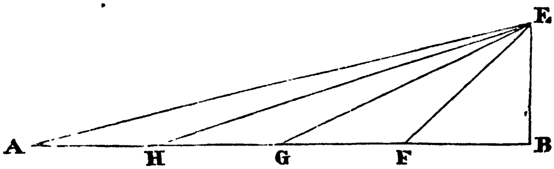


to the angle used. For instance, if the angle 26° 34′ be used, then must the distance, B C, be divided by 2.

The method of determining heights and distances by the tangent table is valuable, as the operations are speedily performed, and with tolerable accuracy; while it enables us to dispense with logarithmic tables and trigonometry.

The pocket sextant is very useful when taking off-sets: set the index to 90°, and walk along the station line; then, when you wish to ascertain at what point any mark or object becomes perpendicular to the station line, you have only to look through the sextant at the left-hand object, and move forward or backward until the two objects, namely, the off-set mark and that on your station-line, are brought to coincide. Or, if you wish to lay off a line at right-angles to another, send your assistant with a staff in the required direction, and having set the index at 90°, cause him to move right or left until his staff and your other mark are made to agree.

The student ought to know the principle upon which the tangent table is formed. In the figure below, B E is perpendicular to A B; and A H, H G, G F, and F B, are each equal to B E; join E F, E G, E H, and E A. Then,—



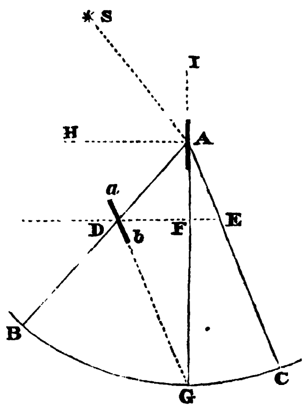
1st radius	: F B	:: tangent $\angle$F	:	B E.
2nd „	: G B, or 2 B E	:: tangent $\angle$G	:	B E.
3rd „	: H B, or 3 B E	:: tangent $\angle$H	:	B E.
4th „	: *E B	:: tangent of the angle	:	B E.

Therefore,—

		Natural Tangent.	
Tangent $\angle$F = radius	=	1.	= 45° 0′
Tangent $\angle$G = $\frac{\text{radius}}{2}$	=	·5000000	= 26 34
Tangent $\angle$H = $\frac{\text{radius}}{3}$	=	·3333333	= 18 26
Tangent $\angle$A = $\frac{\text{radius}}{4}$	=	·2500000	= 14 2

PRINCIPLE OF THE SEXTANT.

We may here devote a brief space to an explanation of the principle upon which the sextant is constructed.



Let A B C represent a sextant, having an index, A G (to which is attached a mirror at A), moveable about A as a centre, and denoting the angle it has moved through, on the arc, B C; also, let the half-silvered (or horizon) glass, *a b*, be fixed parallel to A C; now a ray of light, S A, from a celestial object S, impinging against the mirror, A, is reflected off at an equal angle, and striking the half-silvered glass at D, is again reflected to E, the place of the observer's eye, where the eye likewise receives, through the transparent part of that glass, a direct ray from the horizon. Then the altitude, S A H, is equal to double the angle, C A G, measured upon the limb, B C, of the instrument.

For the reflected angle, B A G (or D A F), = the incident angle, S A I, and the reflected angle, *b* D E, = the incident, *a* D A = D A E = D E A, because *a b* is parallel to A C. Now, H A I = D F A = F A E + F E A; and D A E being equal to D E A, it follows that H A I = D A E + F A E. From H A I and D A E + F A E, take the equal angles, S A I and D A F, and there remains S A H = 2 F A E, or 2 G A C; or, in other words, the angle of elevation, S A H, is equal to double the angle of the inclination of the two mirrors; D G A being equal to G A C.

Hence, the arc on the limb, B C, although only the sixth part of the circle, is divided as if it were 120°, on account of its double being required as the measure of C A B, and it is generally extended to 140°.

SECTION XIII.

ARTIFICIAL HORIZON: METHOD OF USING IT.—PARALLAX. —REFRACTION.—THE REFLECTING SEMICIRCLE.—PRISMATIC COMPASS.—DESCRIPTION AND USE OF THE PLANE-TABLE.

WHEN the altitude of a celestial object is to be taken at sea, the observer has the natural (or sea) horizon, as a line of departure; but on shore, he is obliged to have recourse to an artificial one, to which his observations may be referred: this consists of a reflecting plane, parallel to the natural horizon, on which the rays of the sun, or other object, falling, are reflected back to the eye, placed in a proper position to receive them: the angle between the real object and its reflected image being then measured with the sextant, is *double* the altitude of the object above the horizontal plane.

Such an horizontal plane may be obtained by pouring a quantity of oil, tar, treacle, or other fluid and viscous substance, into a shallow vessel; and, to prevent the wind giving a tremulous motion to its surface, a piece of thin gauze-muslin, or plate-glass, whose surfaces are perfectly plane and parallel, may be placed over it when used for observation.

For portability, an artificial horizon sometimes consists of a plane speculum, or plate of glass, from two to three inches in diameter, fixed in a brass frame standing upon three adjusting screws, by which its surface may be made perfectly horizontal, with the assistance of a small spirit-level, placed on its surface in various positions; observing that the screws be turned, until the air-bubble always rests in the middle of the tube. The under surface of the plate-glass is sometimes unpolished and blackened, so that the image of the sun can only be reflected from the upper surface, which should be carefully polished, and a perfect plane; by this means, the errors that might arise from a defect of parallelism in the two surfaces are avoided.

But the best kind of artificial horizon is that produced by quicksilver, which, being poured into a shallow wooden trough, will always, agreeably to the nature of fluids, preserve an exact horizontal plane at its surface; over this is placed a roof, to protect the quicksilver from the action of the wind, in which are fixed two plates of glass, the surfaces of each being ground perfectly flat and parallel to each other. These are usually packed in a small mahogany box, with a vessel containing a quantity of quicksilver ready for use when wanted.

When an artificial horizon is used, the observer must place himself at such a distance that he may see the object himself, and also its reflected image: then, supposing he is taking an altitude of the sun, the upper or lower limb of its image reflected from the index-glass, must be brought into contact with the opposite limb of the image reflected from the artificial horizon, observing that, when the inverting telescope, with which large sextants are furnished, is used, the upper limb will appear as the lower, and *vice versa*;* the angle shown on the instrument will be double the altitude of the sun's limb above the horizontal plane;† to the half of which, if the corrections for semi-diameter, refraction, and parallax, be applied, the result will be the true altitude of the sun's centre.

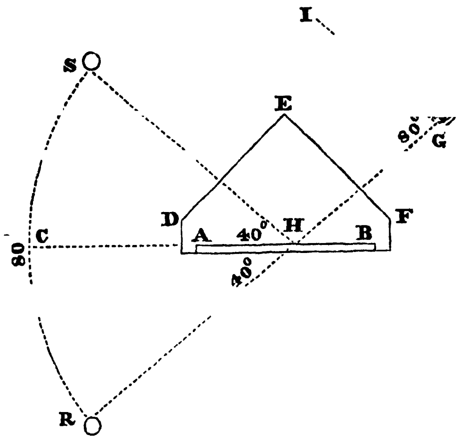
EXAMPLE.

Observed angle	99°	45′	0″
Apparent altitude	49	52	30
Semidiameter	+	15	49
Parallax	+	0	6
	50	8	25
Refraction (always deducted)	−	0	48
True altitude of sun's centre	50	7	37

* When the contact is formed at the lower limb, the images will separate shortly after the contact has been made, if the altitude be increasing; but if the altitude be decreasing, they will begin to overlap; when, however, the contact is formed at the upper limb, the reverse takes place. An observer, if in doubt as to which limb he has been observing, should watch the object for a short time after he has made the observation.

† When observing with a large sextant, there is commonly what is termed the index error to be added or subtracted; this error arises from the glasses of the instrument not being perfectly parallel; and the quantity of their deviation measured on the arc constitutes the index error, which is usually allowed for, in preference to adjusting the glasses to exact parallelism.

The diagram below will illustrate the method of observing altitudes with an artificial horizon:—



Let A B represent the surface of the quicksilver contained in a wooden trough, whose plane is continued to C; DEF the roof, in which are fixed two plates of glass, DE and EF, whose surfaces are plane and parallel to each other: and ○ the sun at S, whose altitude is required. Now the ray, S H, proceeding from the sun's lower limb to the surface of the quicksilver, will be reflected thence to the eye in the direction, H G, and the upper limb of the sun's image, reflected from the quicksilver, will appear in the line, G H, continued to R; and it is a well-known principle in catoptrics, that the angle of incidence, S H A or S H C, is equal to the angle of reflection, G H B; and as the angle, A H R, or C H R, is the opposite angle of G H B, it is, therefore, equal to it, and to the angle, S H C, the altitude of the sun's lower limb above the horizontal plane: so that, if we suppose the angle, S H R, measured by a sextant, to be 80°, the altitude of the sun's lower limb will be 40°, subject to the corrections, as above.

In the example given of observing an altitude of the sun, its semidiameter is added. The apparent diameter of the sun, moon, &c., is the angle under which they appear to an observer situated on the earth; the amount of which depends upon the real magnitude of the object, and its distance from the observer. The sun's semidiameter is set down in the Nautical Almanac, White's Ephemeris, &c. Its mean semidiameter is 16′, which is the quantity used in common practice, as it never varies more than half a minute from that amount.

PARALLAX.

The situation of a celestial body, when viewed from the surface of the earth, is called its *apparent* place, and that part of the heavens where it would be seen, if observed at the same time from the *centre* of the earth, is called its *true* place. The difference between the true and apparent places is termed the parallax of the object. The parallax of an object is greatest at the horizon, and gradually diminishes as the body rises above the horizon, until it comes to the zenith, where the parallax vanishes. It is evident that the altitude of an object seen from the earth's surface, is less than it would be if seen from the centre: hence, the parallax is to be added to the apparent altitude, in order to obtain the true altitude. The sun's mean horizontal parallax is $8\frac{3}{4}''$.

REFRACTION.

The third correction for an altitude of the sun, is on account of refraction. The rays of light which proceed from a celestial body, on entering the atmosphere in an oblique direction, are bent out of their rectilinear course, and incline more and more towards the centre of the earth as they pass deeper into the atmosphere, and hence enter the eye of an observer in a different direction from that of the object, and make it appear higher than its real place. And the difference between the real and apparent places of the heavenly bodies, as affected by the passage of the rays of light through the atmosphere, is called the *refraction* of the object. The more obliquely the rays enter the atmosphere, the more they will be bent out of their rectilinear course, and hence the greater the refraction: consequently, refraction is greatest at the horizon, and ceases at the zenith. Refraction is always to be subtracted from the apparent altitude of an object, because the effect of refraction is to cause bodies to appear higher than they really are; so much so, that the sun, stars, &c., may actually be below the horizon, when they appear above it. In nautical and astronomical works, tables of refraction are usually given. For terrestrial refraction, see *Levelling*. (Section XVIII.)

THE REFLECTING SEMICIRCLE.* [PLATE XIII.]

This is a kind of open sextant, a representation of which is given in plate XIII., by which the angle taken is also protracted with perfect accuracy. It is a semicircle of brass, furnished with an index-mirror, A, and half-silvered horizon-glass, E. There is a small hole at C for the observer to look through. K B is the index-arm, which is pushed open by the hand, and carries with it the mirror, A. D is a vernier, adjusted to a graduated arc at the circumference. On the flat or ruler part there is a diagonal scale of four inches to a mile; and there is a corresponding scale on the fiducial edge. To measure an angle, the observer looks through the hole at C, and sees his left-hand object direct through the unsilvered part at E, while he moves the index-glass, A, by means of the arm, B, until the other object appears on the silvered or lower portion of the horizon-glass, E, by reflection from the mirror, A. The angle is then protracted by means of the instrument itself; for the angle, N K B, formed by the ruler and arm, K B, is equal to the angle observed.

There is this difference in the construction of the semicircle from that of the sextant—that the index-glass being placed at the extremity, instead of at the centre, of a diameter, the angle observed agrees with

* We are indebted to that scientific officer, Lieut.-General Sir Howard Douglas, for this valuable little instrument.

the graduated arc; which is not the case with the sextant. [See Principle of the Sextant.]

This is a very pretty and highly ingenious instrument—applicable to most purposes for which the sextant is used; but I am inclined to prefer the latter, which is, I think, less likely to be put out of order, and when so, is easier of adjustment. It is also more convenient for holding during an observation, and may be considered more portable; as the semicircle must have a case for its protection.

THE PRISMATIC COMPASS. [PLATE I.]

A slight description of the compass may perhaps be useful. The box contains a card, under which, and attached to it, is a magnetic needle; the whole nicely suspended on an agate point, so as to allow of the card playing freely. The circumference of the card should be divided to twenty minutes; but a bearing may be estimated to within three or four minutes, when the box is mounted on a stand. On looking through the slit, at A, the eye, by means of a triangular prism, sees at the same time the thread, B, and the compass-card, in such a manner as to make the divisions on the card seem a continuation of the thread; and the division with which the thread coincides, when the needle is at rest, is the magnetic azimuth of whatever object the thread may bisect. A hinge-joint connects the prism with the box, and enables it to be turned over in a convenient position to fit into the case. The sight-vane, B, has a fine thread stretched along its opening in the direction of its length, which is brought to bisect any object by turning the box round horizontally; the vane also turns on a hinge-joint, and can be laid flat upon the box for the convenience of carriage. A little knob (not seen in the figure) touches a spring, by which the vibrations of the card are checked for speedier adjustment to an object; and C is a little lever by which the card is thrown off its centre; which should always be done when the instrument is not in use, as the constant playing of the needle would wear the point upon which it is balanced, and upon the fineness of the point much of the accuracy of the instrument depends. The milled head, D, fixes the compass, when required. There is a cover to the box, which is about three inches in diameter, and one in depth.

The method of using the instrument is very simple: — Having fixed it on the stand, place it immediately over the station-point, spreading the legs so as to give sufficient firmness; observe that the card is level, or nearly so, in order that it may play freely; then raise the prism, by means of the slide at E, until the divisions of the compass-card are distinctly seen; now look through the slit, A, and turn the box round, until the thread, B, bisects the object you are observing; allow the card to settle, and the division on the card which coincides with the thread of the vane will be the azimuth, or bearing of the object, reckoned from the north or south point of the needle, when the card is divided into twice 180°, as I recommend.

The angular distance between any two objects will, of course, be the difference of their bearings; thus, suppose one to bear 15° N.E., and the other 165° S.E., the angular distance between them will be 150°.

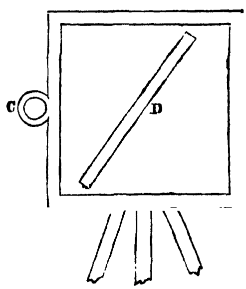
In military sketching, the compass is often supported by the hands, when the little spring, to check the vibrations of the card, is very useful. In windy weather it is necessary to watch these vibrations, and adopt the mean as the bearing sought. When held in the hand, this instrument will give a bearing to within about 15′: but if there be much wind, it will not be nearer, perhaps, than half a degree of the truth.

Dark glasses are sometimes fixed to the prism-case, and a mirror also to the sight-vane: these are used when taking azimuths of the sun. They add considerably to the cost of the instrument; and, being seldom required, I recommend officers to dispense with them, when they want a compass for ordinary surveying purposes.

DESCRIPTION AND USE OF THE PLANE-TABLE.

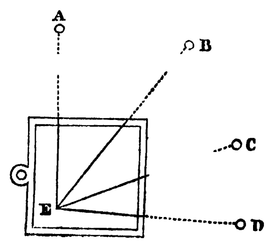
Although the plane-table has been, in a great measure, laid aside by English surveyors, both civil and military, some description of it, with an explanation of the manner of using it, ought to find a place in a manual of military surveying. Before the theodolite came into general use, the plane-table was a capital instrument among surveyors, and continued to be employed both for filling in, and making small surveys, long after the introduction of the theodolite. For military purposes, the chief objection to the plane-table is the inconvenience of carrying it, even under its most portable form, as compared with the prismatic compass and sketching-case; but when surveys are not required to be performed with very great accuracy—such as the class of military sketches—they can be executed with great ease and rapidity by the instrument in question.

The old plane-table was an unwieldy affair, of some 15 or 16 inches square, which has very properly been discarded; and those surveyors who still adhere to this instrument, commonly use a board of from 10 to 12 inches square; they also reject the brass ruler furnished with sights, being contented with a common flat ruler.



In the adjoining figure, representing a plane-table, C is a small compass attached to the board, D is a ruler detached, and lying flat upon it; R is a rim or frame, which serves to confine the paper to the board. The instrument stands upon three legs.

"In preparing the plane-table for use" (says Mr. F.W. Simms), "the first thing to be done is to cover it with drawing-paper; the usual method of doing which is the same as that of covering a common drawing-board, by damping the under side of the paper, and laying it on the board in an expanded state; press the frame into its place, so that the paper may be squeezed in between the frame and the edge of the table; and the paper shrinking as it dries, assumes a flat surface for the work to be performed upon. There is one great objection, however, to this mode of putting on the paper, as, when it has once been damped and strained, it is easily acted upon by any change in the hygrometrical state of the atmosphere. We therefore prefer putting the paper on dry, taking care to keep it straight and smooth whilst pressing the frame into its place; but it must be acknowledged that this cannot be done so nicely as when it is damped. We have been informed that, if the under side of the paper be covered with the white of an egg well beat up, it may be laid on the board with the greatest nicety; and that when so prepared, it is not easily affected by atmospheric changes."



To show the manner of using the plane-table, we will suppose that a military sketch of a portion of country is to be made, and that the first proceeding is to determine the situations of certain points, as A, B, C, D, and E. This is effected by measuring angles from each end of a base line, and determining the positions of the points by intersections, the same as if working with a theodolite or compass.

Let the line, A E, be considered as the base, whose length is to be ascertained by the chain or pacing. Set up the instrument at E, making it as level as possible, by shifting the legs, judging by the position of the compass-card when the board is nearly horizontal. Draw a line upon the paper, and lay off the distance from E to A; then insert a stout needle, fixed in a piece of wood, through the point E into the table; and having laid an edge of your rule along the line, E A, turn the table in its socket, until the distant point, A, is found to be in line with the edge of the ruler; in which position the table must be firmly clamped, by means of a screw for that purpose. Observe the reading of the compass while the table is in that position, and you will afterwards, wherever you may be, always have it in your power to set the table parallel to its first position, by giving the compass-card the same reading; and also be able to check your future operations. Keeping the edge of the ruler touching the needle, move it until it is in line with B, with C and D, drawing lines in succession in the directions of those objects.

This effected, the table is removed to A; and in setting it up, be careful that the point representing

A in the paper be exactly over the station-point, and not the centre of the board. Fix the needle in the point, A, and having laid the ruler again along the line, A E, turn the table until its edge is found to be in line with the distant point, E; when the reading of the compass will be found the same as at the former station. Lines are then drawn in the directions of B, C, and D, which, intersecting those drawn from E, will give their respective situations on the plan.

If the plane-table is to be used for filling in between points previously fixed, some of the points are first transferred to a paper on the table; the instrument is then set up at one of those points, and, being turned round until a line joining that with another of the points is seen along the edge of the ruler to cut the distant object, the figure or lines transferred to the paper on the board are then known to correspond with those on the ground. The reading of the compass-card is then noted, and afterwards, at any point where the table may be set up in the course of operations, it will always be parallel to its first position, when the compass-card has the same reading.

To determine any particular place, such as the bend of a road or river, from whence two or more points already fixed can be seen, it is only necessary to set up the table over the point to be found, and turn it till the compass has the same bearing as at any one of the stations; when the sketch on the table will be parallel, or correspond with the ground, if there is no local attraction to interfere with the needle. Clamp the table, and fix a needle in the point representing one of the stations; place the ruler in contact with this needle, and then turn the ruler until the station is seen along its edge, when a line is to be drawn on the paper. The needle is then removed to another station on the board, and, the same proceeding being gone through, the intersection of the two lines drawn on the board will give the required point. But, as a proof of its correctness, a third line from another station should, if possible, be obtained, which ought to pass through the same point.

It is perhaps unnecessary to dwell longer upon the plane-table, as the few hints above given will put any one in the way of using it, should he have occasion to do so; but I cannot omit some useful observations, with which I have been furnished by a very able surveyor, Mr. E. B. Metcalf, Professor of Military Drawing at Addiscombe College; who states that, "to be convenient for military purposes, the table should be small, not exceeding eleven or twelve inches square; having a frame (which may be divided into inches and tenths, to serve as a scale), to lift off to enable the tracing or paper to be laid on the board; which frame may be confined by means of buttons, or a piece of fine whipcord. The table should be of pear or lime-tree, as those woods do not easily warp, and are besides soft, so as to enable the needle to be inserted easily; the needle must be fixed into a piece of wood for convenience, and the ruler ought to be divided for laying off distances, and rendering a pair of compasses unnecessary, these being inconvenient to carry, unless of the folding kind. A portable compass, which may be carried in the pocket, is best for the purpose of using with the table.

"The simplest support for the table is a stout ash stick, four or five feet long, to suit the height of the observer, shod with iron; having about eight or nine inches from the point a piece of iron fixed at right angles, and about six or seven inches long, provided with a pointed shank, which enters the ground as a support to the staff, and also enables the operator to fix it more firmly by treading on the shank; but three legs are recommended, as giving greater stability to the table than can be obtained by one stout one, even when provided with the additional shank.

"A person may make a plane-table for himself, by taking a piece of board, or mill-board, and pasting several pieces of stout paper round a stick, and to the board. When the pasting is dry, the wood can be withdrawn, when a tube will be left, into which the staff for the support of the rough table may be inserted. This rude expedient would be found to answer very well for military sketching; and the instrument might last a long time with proper care."

SECTION XIV.

OF THE PROTRACTOR AND PLOTTING. FURTHER DESCRIPTION OF THE THEODOLITE, WITH AN EXPLANATION OF ITS SEVERAL ADJUSTMENTS.

For laying down or protracting angles measured with a theodolite, or other instrument by which they are obtained to minutes, or less, of a degree, a superior kind of protractor becomes necessary; for, as we have already observed, it is of little avail that angles are taken to minutes, unless they can also be laid down on paper with corresponding accuracy. Accordingly, metal protractors of both circular and semi-circular forms, and furnished with a vernier, are used.

In Volume I. of Papers on Subjects connected with the Duties of the Royal Engineers, is one on protractors, by Mr. Howlett, which I shall quote at length, as it contains some just observations on them; his method of plotting also deserves to be generally known. He says:—

"The circular protractor, at the price of from four to eight guineas, is generally considered the most perfect kind of instrument for plotting the angles of a survey; but against this instrument there are the five following objections:—

"It is only steadied by being attached to the paper by pins; and in moving the arm it is liable to shift.

"As the vernier has to be set while the protractor is fixed on the paper, and cannot be held to the light, it is next to impossible, in some positions, to see the divisions; or, if the protractor be taken from the paper, time is lost and error is caused by having to replace it on the working meridian.

"When the whole set of angles required are set off and numbered, they have to be transferred to the station, one after the other, with parallel rulers; in doing which much error creeps in, both while setting the edge of the ruler against the points, and then in shifting the ruler along to a distant part of the paper.

"It is a very delicate instrument, liable to be soon strained and rendered unfit for use.

"Lastly, the general inaccuracy of the method which this instrument implies — for the sources of error are so many that the work cannot be brought to close in a satisfactory manner—and when done, it is little better than a survey plotted by a common protractor, where the degrees and half degrees only are marked.

"The old surveyors of the Ordnance used the semicircular protractor, and transferred the instrument itself to the station, by means of large parallel rulers fixed on the paper; and having set the arm to the required angle, they drew the line against the arm itself, some inch or two of which was made in a line with the centre and zero. This excellent way was, however, rendered inaccurate by the impossibility of preventing the joints of the large three-bar parallel rulers from becoming loose; and much inconvenience was felt in consequence of the rulers, even at a great price, not extending sufficiently wide to carry the protractor over a small sheet of plotting cartridge-paper.

"These methods of plotting a survey to a small scale, where an error of ten minutes is not very striking, may answer, and escape censure; but in making surveys of several thousands of acres for content, to a large scale, I have found all the methods above described exceedingly awkward, and not at all adequate to the plotting of the perfect work done by the theodolite. In making surveys of estates and parishes, while on half-pay, I suffered much for want of a better system of plotting than any I could find, after making every inquiry, and searching books on the subject. Such methods as these do not meet the exigences of practical men, and hence it is usual to employ the chain alone. The theodolite is very little used among private surveyors: they reject the system altogether; and, indeed, many use the chain so skilfully that, under ordinary cirumstances, it leaves nothing better to be desired. The theodolite is, however, an invaluable instrument; and if the proper use of it, together with a more satisfactory method of plotting, were more generally known among private surveyors, much of this prejudice would certainly give way.

"Anxious to discharge the duty confided to me in the most beneficial manner, I have given much study to this as well as to other branches of my duty, and have the honour to submit, at least for trial and discussion, the following very cheap and simple means; which are, in all respects, the nearest approach to perfection that I can contrive:—

"The pattern semicircular protractor, at the price of no more than £2 17*s.*, was contrived and made from my drawing and instructions, some few years ago, and must be too well known in the department to need description.

"As, when away from home, it seldom happens that the surveyor can obtain a good drawing-board, or even a table, with a good straight edge, I fix a flat ruler, A, to the table, B B B (plate XIV. fig. 1), by means of a pair of clamps, C D, and against this ruler I work the pattern square, E, one side of which has the stock flush with the blade; or, if a straight-edged board be at hand, then the square may be turned over, and used against that edge instead of the ruler, A. Here, then, is the most perfect kind of parallel ruler that art can produce, capable of carrying the protractor over the whole of a sheet of plotting paper of any size, and may be used upon a table of any form. It is convenient to suppose the north on the left hand, and the upper edge of the blade to represent the meridian of the station.

"This protractor is held in the hand while the vernier is set, which is an immense comfort to the sight; and it will be seen that, as both sides of the arm are parallel with the zero and centre, the angle may be drawn on the paper against either side, as the light or other circumstances may render desirable.

"From this description, and a mere glance at the plate, it is clear that angles taken with the theodolite, can be transferred to the plot as accurately as the protractor can be set, namely, to a single minute; and that, too, in a rapid and pleasant manner.

"By means of the notch at the end of the arm, this instrument may be used in the manner of a circular protractor, should a square not be at hand.

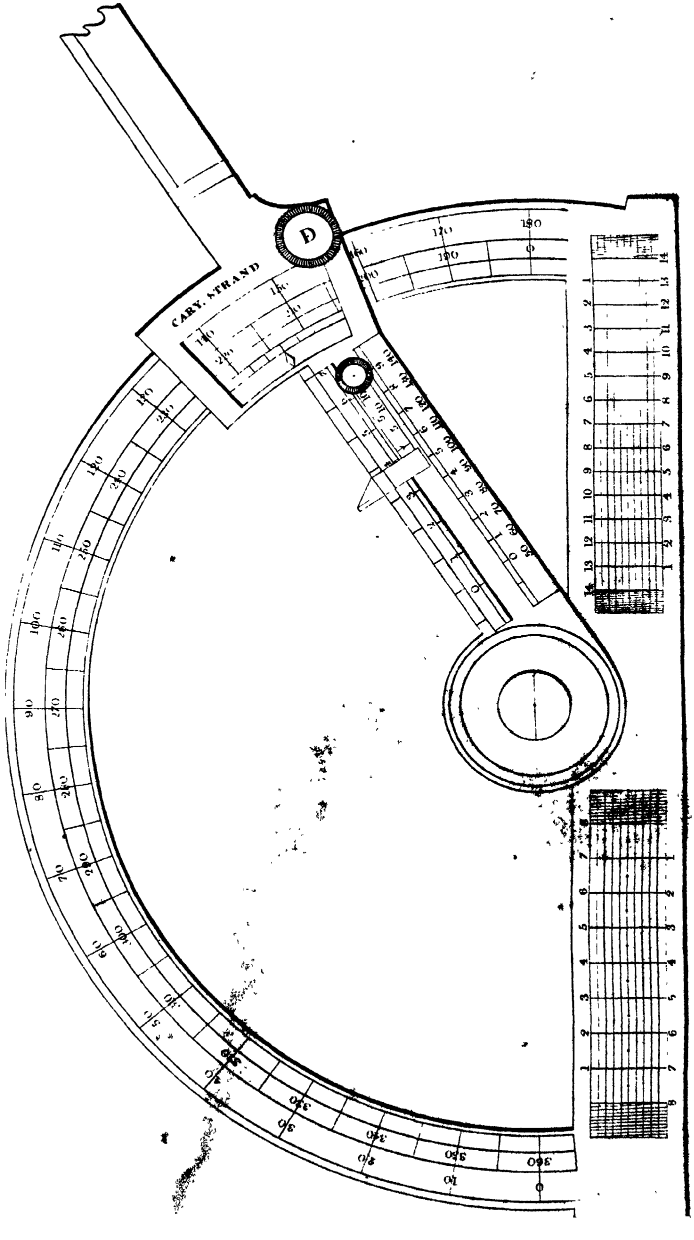
"This protractor is specially for plotting a survey, and therefore is figured from left to right; but should it be required for other purposes, to set off an angle from right to left, then mark off the supplement of that angle."

The experience of practical men is always highly valuable, and we are indebted to Mr. Howlett for the above useful remarks. His method of carrying the protractor forward, is excellent, and the instrument itself is a very good one. Another protractor, however, on a similar principle, but possessing additional advantages, has been put into my hands by Mr. E. B. Metcalf, which I strongly recommend to the attention of surveyors, both military and civil.* (Plate XV.) The radius is 5¼ inches. Its arc is numbered from left to right 180°, and from right to left to 360°, by which the supplement of any arc to 360° is at once seen. Each degree is divided into three parts of 20′, and the vernier reads to one minute. When set to 180°, it may be used with great exactness as a circular protractor, if so required. Thus far the instrument before us differs but slightly from Mr. Howlett's; but, by an ingenious contrivance, the radius is rendered the means of setting off distances at the same time that it protracts an angle: scales of 2 inches to a mile, both in *feet* and *links*, being marked upon the radius—having a *double vernier*, reading on one side to a single *foot*, and on the other to one *link*. Diagonal scales corresponding with these are marked on the ruler part of the protractor.

The manner of using the instrument is thus:—Let us suppose that the stations of a road-survey are to be laid down. Adjust the radius-vernier to the distance wanted, and turn the milled-head to keep it there: then set the vernier of the protractor to the required angle, and fix it by the milled-head, D: the instrument has only to be laid upon the paper, over which it is to be pushed by the T rule (according to Mr. Howlett's mode), until zero on

* This gentlemen was for a considerable time employed on the Trigonometrical Survey of England; and it was then that he contrived his valuable addition to the protractor.

PLATE



the bevilled or fiducial edge of the radius agrees with the station-point. A common needle, set in a bit of wood for a handle, is now used to prick off the length of the station, and a line is drawn as far as the point marked. In this manner the distance is measured off with greater accuracy than could be done by the usual method of taking it with a pair of compasses from a scale of equal parts, while the process is also shortened; besides, there is the further advantage of never having a greater length of line drawn on the paper than is actually wanted, and, consequently, the risk of adopting a wrong one is removed. For long stations, the *centre* of the protector may be used instead of the zero given on the radius, the distances being taken along it from the centre. The object of having scales of feet and links, is to enable the surveyor to use the Gunter chain, or that of 100 feet, at pleasure, and he has only to note in his field-book whenever one chain is exchanged for the other, to avoid all chance of mistake. Much time may be saved by making use of the 100 feet chain on level ground; but, when a surveyor is working with only one assistant, and, consequently, takes one end of the chain himself, the heavy chain becomes very fatiguing when surveying over a hilly country.

It is scarcely necessary to point out that a surveyor may have his scales on the radius to suit the nature of his work. A military man, for instance, might have one side divided to 4 inches and the other to 3 inches, to a mile, which he would probably find more useful than having one side in links: then, by taking half the quantities, he might work to a scale of 2 inches or 1½ inch to a mile, if requisite. The numbers, 50, 60, 70, &c., have reference to using the centre of the protractor instead of the zero, when long distances are required.

Notwithstanding the superiority of moving the protractor forward by means of a T ruler, I think military men will often be disposed to use the large three-bar parallel ruler on account of its portability. One bar is fixed, either by means of leaden weights or small screws, while the others advance over the paper, pushing forward the protractor.

There is another method, which ought to find a place here, being still more suited to our wish, for portability, as it requires no ruler to work the instrument with. A number of parallel lines are ruled upon the paper at about an inch or so apart, to represent meridians, which are marked *north* and *south*. The semicircular protractor is then set to the required angle: a point is next marked on the paper for the first station, and the protractor is then adjusted to any convenient meridian so that the ruler part or base of the instrument may coincide with one of the meridian lines, while the bevilled or fiducial edge of the arm cuts the station-point: a line has then to be drawn along the edge of the arm through the station-point, and the bearing is laid down. A common flat ruler is, however, useful in this method of protracting. Lay the ruler along any convenient meridian; and, having set the protractor to the required bearing, place its base, A B, along the edge of the ruler, D E (see fig. 2, plate XIV.), so that the arm, G, may not touch the station, C; the ruler, D E, is then kept steady, while the protractor is gently pushed along until the edge of the arm agrees with the station-point, C. It is to be remarked, however, that these two last methods do not enable us to use the divided radius of the improved protractor for laying off distances; as we cannot adjust zero to the station-point, unless we have the means of pushing the instrument *forward* as well as *laterally*.

FURTHER DESCRIPTION OF THE THEODOLITE, WITH AN EXPLANATION OF ITS SEVERAL ADJUSTMENTS. [SEE PLATE V., PAGE 21.]

The *telescope* should be of the achromatic kind, in order to obtain a larger field and a greater degree of magnifying power. In the focus of the eye-glass are two hairs at right angles to each other; they are of spiders' thread, and attached by means of a little gum to a circular brass ring, smaller than the tube of the telescope. In this

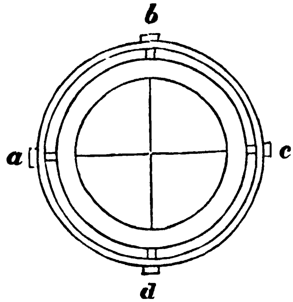


figure the outer circle represents a section of the tube of the telescope; the inner, a brass ring to which the threads are attached, fixed to the tube by the four small screws *a*, *b*, *c*, *d*, near the eye-end of the telescope. If the screw at *a* be eased, while at the same time that at *c* is tightened, the ring will be moved to the right; and in the same way it may be moved up or down by turning the screws at *b* and *d*. The object of this contrivance is to place the intersecting point of the threads in the centre of the telescope—its axis.

The object-glass of the telescope is moved by means of a milled nut, M, in order to suit the eye of the observer, and his distance from the object. The telescope rests on supports, called Ys, which are fixed to the vertical arc, and so formed as to be *tangents* to the cylindrical rings encircling the tube of the telescope, and consequently the *bearing* is only upon two points in each Y.

The vertical arc, V, is graduated on one side to half degrees, and provided with a vernier reading to one minute. It is numbered each way from 0 to 45° or 50°, for taking angles of altitude or depression. On the other side of the vertical arc, a range of divisions is sometimes given for reducing hypothenusal lines to horizontal ones, or showing the difference between the hypothenuse and base of a right-angled triangle, always supposing the hypothenuse to consist of 100 equal parts; therefore, the number of feet to be deducted from each chain's length in measuring up or down a slope, in order to reduce it to the true horizontal distance, is seen at once.

The horizontal circle, H, consists of two plates, one moveable on the other. The upper, or index-plate, carries a vernier scale, adjusted to the divisions of degrees and half degrees of the lower plate. The index-plate (together with the compass, vertical arc, and telescope,) turns on its axis independent of the lower plate; which latter turns on the same axis, but is fixed in any position by tightening the clamping-screw, A. The screw, P, fastens the two plates together, when the upper plate may be made to move a short distance by turning the tangent-screw, N. The horizontal circle is divided into half degrees, and numbered from 0 to 360° or 180°. The vernier scale subdivides the half degrees to one minute or less, according to the size of the instrument.

The compass is fixed on the upper plate. It is divided to 360°, numbered contrary to the horizontal circle. The letters E and W are generally transposed; the use of which is that, in taking a bearing, 50° west for instance, the needle remaining stationary shows 50° towards W, or west. But with the letters properly placed, the needle would point to 50° between the N and E points.

THE ADJUSTMENTS OF THE THEODOLITE.

Every one using the instrument ought to be able to adjust it for himself. The first adjustment is that of the line of sight, or of collimation as it is termed; which is to place the intersection of the cross hairs exactly in the centre or axis of the cylindrical rings of the telescope resting on the Ys. To effect this, place the theodolite on its legs, and direct the telescope so that the centre of the horizontal hair shall coincide with some well-defined part of a distant object; then turn the telescope in the Ys, till the level is uppermost; observe then whether the horizontal hair still coincides with the object, if so, the hair is in its right position; if it do not so coincide, correct *half* the difference by moving the hair, which motion is effected by easing one of the hair-screws, *a*, *b*, *c*, and *d*, and tightening its opposite; after which, turn the telescope in the Ys till the level tube is underneath, and make the horizontal hair coincide with the object, by moving the vertical arc, V; again turn the telescope till the level is uppermost, and if the hair do not cut the same part of the object, the above operation must be repeated till, in both positions of the telescope, the horizontal hair cuts the same part of the distant object. The horizontal hair being thus adjusted, turn the telescope until the other hair is placed in an horizontal position, and proceed as before. When the two hairs are thus adjusted, their point of intersection will coincide exactly with the same point of the distant object while the telescope is turned round; and the hairs are not properly adjusted till this is effected.

The second adjustment is that which puts the level attached to the telescope parallel to the rectified line of collimation. The clips, *i i*, being open, and the vertical arc clamped by turning the screw, C, bring the air-bubble of the level to the centre of its glass tube, by turning the tangent-screw, D, which gives a slow motion to the vertical arc; this done, reverse the telescope in its Ys, that is, turn it end for end, which must be done carefully, that it may not disturb the vertical arc, and if the bubble resume its former situation, in the middle of the tube, all is right; but if it retire to one end, bring it back one half by the screw, R, which elevates or depresses that end of the level, and the other half by the tangent-screw, D, of the vertical arc: this process must be repeated until the adjustment is perfect.

The third adjustment is that which makes the azimuthal axis, or axis of the horizontal circle, truly vertical.

Set the instrument as nearly level as can be done by the eye, fasten the centre of the lower horizontal plate by the clamping-screw, A, leaving the upper plate at liberty, but move it till the telescope is over two of the parallel plate-screws; then bring the bubble of the level under the telescope to the middle of the tube, by the screw, D; now turn the upper plate half round, that is, 180° from its former position; then, if the bubble return to the middle, the plate is horizontal in that direction; but if otherwise, half the difference must be corrected by the parallel plate-screws, over which the telescope lies, and half by elevating or depressing the telescope, by turning the tangent-screw, D, of the vertical arc: having done which, it only remains to turn the upper plate forward or backward 90°, that the telescope may lie over the other two parallel plate-screws, and, by their motion, set it horizontal. Having now levelled the horizontal circle, by means of the telescope level, which is the most sensible upon the instrument, the other air-bubbles fixed upon the vernier plate, may be brought to the middle of their tubes, by merely giving motion to the capstan-headed screws at each end of them.

The vernier of the vertical arc may now be attended to: it is correct, if it points to zero, when all the foregoing adjustments are perfect; and any deviation in it is easily rectified, by releasing the screws by which it is held, and tightening them again after having made the adjustment; or, what is perhaps better, note the quantity of deviation as an index error, and apply it, plus or minus, to each vertical angle observed. This deviation is best determined by repeating the observation of an altitude or depression in the reversed positions, both of the telescope and the vernier plate: the two readings will have equal and opposite errors, one half of the difference being the index error.

Such a method of observing angles is decidedly the best, since the mean of any equal number of observations, taken with the telescope reversed in its Ys, must be free from the effects of any error that may exist in the adjustment of the vernier or zero of altitude.

It is of great importance that the telescope and vertical arc should move in the same vertical plane: in small theodolites, this is provided for by the construction, and no means are afforded for making any alteration; but larger instruments are furnished with screws for this adjustment. To prove the accuracy of the vertical arc, suspend a weight by a long plumb line from a branch of a tree, or otherwise, and adjust the cross hairs upon it; then, by means of the elevating screw, cause the vertical arc to rise, and observe whether the cross hairs continue on the line while the vertical motion continues. Or fix them on the angle of a lofty building, and raise or depress the telescope, when the cross hairs will continue to move on the angular line, if the adjustment be perfect. For depression, a reflection of the same angle of a building from an artificial horizon, will serve as a test.

For a fuller description of the theodolite, if necessary, as also of other instruments, I recommend Mr. F. W. Simms' treatise on the principal mathematical instruments employed in surveying, levelling, astronomy, &c.; a work likely to be very useful, as the author combines, with a perfect knowledge of the subject he treats, a style of expressing himself, at once clear and concise. The same writer has likewise published a valuable little book on levelling.

SECTION XV.

RÉSUMÉ ON SURVEYING INSTRUMENTS.—OF THE MERIDIAN LINE.—TO SURVEY INTRENCHMENTS AND FIELD-WORKS.—PRACTICE OF CIVIL SURVEYORS IN SURVEYS OF LIMITED EXTENT.

Having given a sufficiently minute description of the instruments commonly used by military men, and explained their several adjustments, it only remains for me to point out those among them that will be found most generally useful.

With regard to the theodolite, which is unquestionably the best instrument employed in surveying, it may be observed, that an officer seldom finds it necessary to provide himself with one; as, whenever he is employed on an extensive survey, proper instruments will be furnished him for the duty: besides, the theodolite is much too cumbersome an instrument to form any part of his personal equipment.

Field instruments, as the compass, sextant, &c., he must have of his own. I think that, in the course of the preceding pages, it has been sufficiently proved, that a good prismatic compass is adequate to every purpose of ordinary military surveying; it is, in fact, a kind of pocket-theodolite. With a tripod stand, which is essential, we are enabled to obtain bearings with considerable accuracy — at least, they will be near enough to the truth for any military sketching. Moreover, it must be borne in mind, that an officer rarely carries with him a protractor, furnished with a vernier; and therefore a few minutes of error in taking an angle, or bearing, cannot be to him a matter of much moment.

The result of our observations goes to show, that a person wishing to limit himself to a single instrument, will do well to select the compass in preference to any other.

The box-sextant is an excellent little instrument, as I think we have proved; but, unlike the compass, it will not do alone. With it we can neither lay down a meridian line, nor can we find our place on a plan, by knowing the situations of two others: both objects of absolute necessity for military sketching.

I shall say nothing here of the reflecting semicircle, as the remarks on the sextant apply equally to that instrument.

Instrument-makers have various *additions* and *improvements* both to the compass and sextant; but I recommend them to be in their simplest form: I would not even have any contrivance whatever for levelling the compass-box, which is easily effected by moving the legs of the stand. The expensive toys that adorn some of the opticians' shops, with all their complicated machinery, are only worthy to be considered as curiosities for the amusement of fanciful amateurs. I never saw a practical man use any but simple surveying instruments. It is a maxim, that engines and machines for military service, should always be simple in their construction, and easily repaired when put out of order.—Our surveying instruments form no exception to the rule.*

OF THE MERIDIAN LINE.

All surveys should have a *true* meridian laid down on them, as well as the magnetic one; which last is variable. Any person using a map or plan, immediately begins to refer all imaginary lines connecting towns or villages, as well as the directions of roads, rivers, ridges of hills, &c., to the cardinal points—this is his first step towards an acquaintance with the country by means of a map.

When the *variation* of the needle is known correctly, a true meridian line is laid down with sufficient accuracy for ordinary military surveys by

* A reflecting instrument, more simple in its construction than the pocket-sextant or reflecting semicircle, and far more portable than either, as it occupies only the bulk of a folding foot rule, has been recently invented by the Rev. Frederick Glover, Rector of Charlton, in Dover, which has not yet been made public; but I trust that gentleman will ere long have it brought out for the benefit of military men and travellers, who would find it very useful for other purposes besides taking angles.

means of a good compass; as we have then only to draw a line, making an angle equal to the amount of variation, with the magnetic meridian by which we have been working. But the exact variation is not so easily obtained as some may suppose; as the most careful observations, with very delicate instruments, will often give fallacious results, owing to local attraction or other causes, of which we are not conscious. For instance, at sea the body of the ship exercises so much influence on the needle, that an observation may be thrown some degrees wide of the truth.

In 1838, being desirous to know the exact variation at London, I applied to the Royal Observatory and obtained the amount of it at the time their latest observation was taken, namely, a few months previously: it was then about 24° 6′ W. I mention this, here, as 23° 30′ is very generally considered to be the variation at present with us; and I find that in France they are not more exact; for the *Aide Mémoire* of Captain Laisné of the Engineers, gives 22° 4′ as the variation in 1835, or about 2° from the truth.

While on the subject, I may mention that the cause of the variation has never been satisfactorily ascertained. If our records be correct, the variation was at London in 1580, 11¼° E.; in 1622, 6¼° E.; in 1634, 4° E. Since which, it has continued gradually deviating westerly, at the rate of about 12′ annually, but is now retrograding. It is to be observed, however, that the variation alters as we change our place on the earth's surface.

But this is something like a digression. I was going to extract from Major Sir T. L. Mitchell's little work on surveying, a mode there pointed out of laying down a meridian line, which is very simple, and will do very well for ordinary occasions; it is, moreover, particularly suited to an officer, who has seldom good astronomical instruments at command.

"Let a plummet be suspended, so as nearly to touch the smooth surface of a table placed truly horizontal, from the point of a thin but steady rod attached to the table, and inclined over the middle of it at an angle of about 45°. When the plummet is still, mark the point exactly under it on the table. The table may then be conveyed to any point laid down on the plan, and adjusted to the horizontal position by means of the plummet, which will, in that case, cover the point previously marked. At 9 o'clock, *a. m.*, and at 3, *p. m.*, according to a good time-piece, mark on the table the point of the shadow of the rod, and draw a line from each of these points to the point under the plummet. These lines, if the watch is correct, will be equal in length, and at the equator would form one straight line, a perpendicular to which, at the plummet point, would be in the direction of the meridian; and, at other parts of the earth, the meridian will be in the direction of a line bisecting the angle formed by shadows of equal length. This simple method may be adopted with equal accuracy without a time-keeper, by marking the point of the shadow some hours before mid-day, and of that shadow also which is cast of equal length in the afternoon. This corresponding length of the afternoon shadow may be found by the repeated application of any measure equal to the length of the morning shadow.

"It may be more convenient to mark shadows at different intervals in the morning, in order that one corresponding in length may be found with less delay in the afternoon; or, for the sake of greater accuracy, several corresponding respectively to distances marked by points of morning shadows. One line will bisect all the angles contained between equal sides, and that line will be in the direction of the meridian.

"When this line has been determined on the table, it may readily be connected with the ground, by inserting needles at the two extremities, and looking along them to any object on the horizon with which they may coincide. When that object happens to be one laid down on the plan, the line between it and the station will be that of north and south; when it is not a point laid down on the plan, the angle must be observed between it and any fixed point: the direction of the meridian line may then be laid down by protracting that angle."

TO FIND THE VARIATION OF THE NEEDLE.

The following method of finding the variation is sufficiently exact for ordinary purposes, but not accurate enough for fixing a true meridian, owing to the uncertainty of the refraction; but if the sun ascends or descends with little obliquity, the error will not then be very considerable.

When the sun's lower edge or limb is a semi-diameter above the horizon (at which time its centre is really about on the horizon, although it is apparently elevated, on account of the refraction of the atmosphere), take the bearing of its centre from the N. or S., whichever it is nearest, with an azimuth compass. The prismatic surveying compass will do, if provided with what is termed an azimuth. The thread is made to bisect the sun's disc, and the observed bearing subtracted from 90° will be the sun's magnetic amplitude, or distance from the E. or W. points by the needle.

Next calculate the sun's true amplitude for that day, thus:—

To the log. secant of the latitude, rejecting the index, add the log. sine of the sun's declination, corrected for the time and place of observation, from a table for that purpose; their sum will be the log. sine of the true amplitude. Or by another rule:—

As the co-sine of the latitude is to the radius, so is the sine of the sun's declination at setting or rising to the sine of its amplitude from the W. or E. To be reckoned from the east in the morning, or the west in the afternoon, and it will be N. or S., as the sun's declination is N. or S.; and the distance in degrees and minutes between the true E. or W. and the magnetic is the variation of the needle.

Observe, if the true and magnetic amplitudes be both north or both south, their difference is the variation; but if one be north and the other south, their sum is the variation: and to know whether it be easterly or westerly, suppose the observer looking towards that point of the compass representing the magnetic amplitude; then, if the true amplitude be to the right hand of the magnetic, the variation is east; but if to the left hand, it is west.

EXAMPLE I.

Required the sun's true amplitude on November 6th, 1828, *in latitude* 48° 21 .

Latitude.......	48°	21'.......	Secant	0·17745
Declination	16	4 S. .. .	Sine..	9·44210
True amplitude	24	37.......	Sine..	9·61955

Hence the sun rose 24° 37′ south of E., and set 24° 37′ south of W.

EXAMPLE II.

July 3rd, 1828, in latitude 9° 36′ S., the sun was observed to rise 12° 42′ *north of E.: required the variation of the needle.*

Latitude.......	9°	36′	S..........	Secant 0·00613
Declination....	22	58	N..........	Sine.. 9·59128
True amplitude	23	19	N. of E.....	Sine.. 9·59741
Mag. amplitude	12	42	N. of E.	
Variation..	10	37	W., because the true amplitude is	

to the left of the magnetic.

EXAMPLE III.

September 24th, 1828, in latitude 26° 32′ N., and longitude 43° W., the sun's centre was observed to set 6° 15′ S. of W. about 6 p.m.: required the variation of the needle.

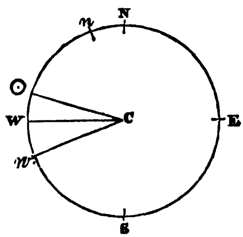
Sun's declination...	0°	33′	S.	
Corr. for longitude	+	3		
Corr. for time 6 *p.m.*	+	6		
Reduced declination	0	42	S...........	Sine.. 0·08696
Latitude.........	26	32	....	Secant 0·04834
True amplitude....	0	47	S. of W.	Sine.. 0·13530
Mag. amplitude...	6	15	S. of W.	
Variation..	5	28	E., because the true amplitude is	

to the right of the magnetic.*

* The necessary tables for the declination and corrections are given in the Nautical Almanac, and in most works on navigation: some of them are also contained in White's Ephemeris. This latter, with the addition of a few more tables, would be very useful to military men, and travellers generally, being so portable.

An excellent way of preventing mistakes, which inexperienced observers are subject to, is to draw a rough diagram; thus, first, a circle to represent the visible boundary of the horizon, and on it to draw such lines as are necessary to render the figure complete; then, it will at once appear how the variation is to be found, whether by addition or subtraction, and on which side of the north it lies. For example:—

We will suppose the variation to be sought at sun-setting. Draw a circle, N. W. S. E., to represent the visible horizon; in the middle of it mark the point, C, for your station; from C draw the line, C W, to represent the true west; then on the north or south side of that line, according as the sun sets north or south of the true west, draw the line, C ⊙, representing the direction of the sun's centre at setting; and another line, C *w*, for the magnetic west, either on the north or south side of ⊙, as it was observed to be, and at its judged distance. Then, by observing the situation of these lines, it will easily be seen whether the magnetic amplitude and true amplitude are to be added or subtracted to give the variation; and on which side of the true north the variation lies. In the present supposition *w* ⊙ is the magnetic amplitude, and ⊙ W the true amplitude: ⊙ W, therefore, must be subtracted from ⊙ *w*, to give *w* W, the distance

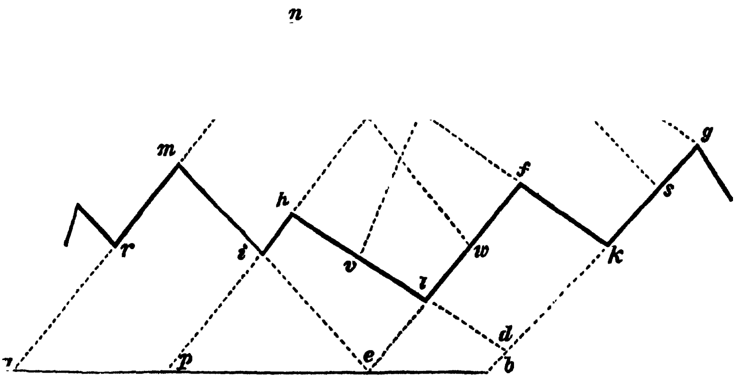


of one from the other; and *n*, the magnetic N., 90° from *w*, must be westward of N. the true north.

TO SURVEY INTRENCHMENTS AND FIELD-WORKS.

The same principles that regulate the survey of a portion of country, or of a military position, serve to guide us in making a plan of intrenchments or military works of any kind.

The diagram below represents an irregular line of intrenchment, with two advanced *flèches*; of which we will suppose that a plan is required.



Measure a base, *a b*, having its extremeties on the prolongations of two lines of the works, when convenient; thus *b* is on the prolongation of *g k*, and *a* upon that of *m r*. Set up marks at *a* and *b*, as also at such of the angles of the intrenchment as may not be sufficiently defined for observations. Draw a line on your paper, and lay off the length of the base; having done which, place yourself at *b*, and measure the angle, *a b g*; protract this angle. Next measure from *b* towards *k*, noting the distance of *d* (prolongation of *h l*); then fix *k*, and measure on to *g*, marking the point, *s*; observe the angle, *g k f*, which lay down. Now return to *b*, and measure to *e* (prolongation of *f l*); observe the angle, *l e b*, and fix the point, *l*, by measurement from *e*; join *d l*, of which *l h* is a continuation; then measure on to *f*, and join *f k*. Next measure from *e* to *p*, along the base line, and observe the angle, *i p e*, and measure from *p* to *i* and *h*; join *e i*, and continue the line towards *m*. Measure from *p* to *a*, observe the angle, *r a p*, and find the points *r* and *m*. Thus far no notice has been taken of the *flèches*; but, while at *g*, the angle, *k g o*, should have been observed, and the prolongation of *i h*, intersecting *g o*, fixes the point, *o*. The directions of the faces of this *flèche* are determined by *v* and *s*. For the *flèche*, *n*, its salient is determined by an angle taken at *f*, intersecting the prolongation of *r m*, while the right face falls on *l f* at *w*. We have, lastly, only to ascertain the lengths of the faces of these two advanced works, and the task is complete.

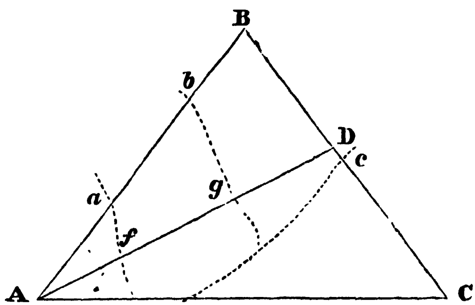
Either the sextant or compass may be used for taking the angles, but if the ground is tolerably level the former instrument will give them most correctly. The linear measurements should be performed with a chain and a measuring-tape, or, if these are not at hand, a rope may be used. Pacing is not suited to such an operation, and can only be admissible when other means cannot be employed.

A plan of any military work requires to be accompanied by profiles or cross vertical sections, showing the height and thickness of its parapets and ramparts, width and depth of the ditches, steepness of the slopes of the work, &c. But this part of the business belongs to *levelling*, and will be found in its proper place. [See *Levelling*.]

PRACTICE OF CIVIL SURVEYORS IN SURVEYS OF LIMITED EXTENT.

I shall now notice briefly the difference between military and civil surveying. At the first view it would seem that, where a delineation of any part of the surface of the earth is required, the same methods, or nearly so, must be adopted to attain our object, whether for civil or military purposes. This is true so far only as general maps, comprising a large extent of country, are concerned. Such maps can be obtained no otherwise than by triangulation, in the manner already described. But for minor and, as they may be styled for the sake of distinction, local purposes, the paths of the civil and military engineer are no longer the same, at least in England; for the former have almost universally adopted a mode of surveying without using any instrument, save the land-chain; while we, on the contrary, throw aside the chain and adhere to our instruments.

The method pursued by the civil surveyor is most simple, and the following example will serve to explain it. Let A, B, and C be conspicuous objects, forming a triangle, as church steeples, wind-



mills, &c., and that they are visible from each other; we can then, by means of marks to keep us in direct line (sticks with bits of paper stuck on them), measure the distances between those points; and, consequently, we can lay down on paper a triangle perfectly similar to the one formed by our three objects, A, B, and C. While measuring along the sides of the triangles, the distances at which the lines cross all roads, streams, fences, &c., running transversely, are entered in a field-book; thus, when measuring from A towards B, at 1000 yards, we come to the road at *a*; 900 yards further, to *b*; and so on for the three sides of the triangle. A line is next to be run across the triangle, starting, let us suppose, from A, and proceeding in any convenient direction. On this line, at 800 yards, we cross the road at *f*; and 1100 yards further we come to another road, *g*; continuing on, we strike the side, C B, of our triangle at D, which is found to be 200 yards from the road at *c*. To lay down the line, A D, we have only to set off 200 yards from *c*, which fixes D, and then to draw the line from A; after which the points, *f* and *g*, are fixed, by laying off 800 and 700 yards respectively. Another line is then run in any advantageous direction for intersections; and thus the operations continue, until sufficient lines are obtained to enable the surveyor to plot all he requires. When measuring over rising or falling ground, due allowance must be made for the difference between the hypothenuse and base of a right angled triangle. This he usually estimates; and he has always a check upon his cross measurement whenever he falls on a line already laid down.

Such is nearly the system of civil surveyors generally throughout this country, whether the required survey be that of a parish, or of great extent, as for a railway. In the latter case he takes his triangles from the *secondary* ones of the Ordnance survey; but for a very small survey, as of a parish, he must form his own triangle: this he does either by measuring between the three points, as already noticed, which answers very well in an open and flat country; otherwise he measures one side of his triangle as a base, namely, that where the ground is most level, and determines the third point by an angular intersection, using for this purpose a theodolite or pocket-sextant. By employing an instrument, such as the theodolite, for fixing the third point, there will always be less of error if the country be at all hilly, than there would be in obtaining it by measurements of all the three lines, on account of the necessary reductions to the *horizontal* distances in the latter case.

It is to be observed that, as regards surveying for military purposes, it is requisite that all methods should be general in their application; equally suited to all countries, whether mountainous or flat, wooded or bare, enclosed or otherwise. How could our civil method of surveying be practised in the jungles of India,* or amid the Alps and Pyrenees? Another objection to it for military purposes is the necessity of using a field-book, from which the plan has afterwards to be plotted, as a line must be laid down along its entire length before it can be made use of; whereas, our military sketches are quickly completed in the field, and we return with a plan prepared to lay before the General. Another point is that the civil engineer is generally either surveying for content, or accurately

* In order to run the necessary lines, the surveyor is obliged to cut his way through copse wood, plantations, &c., thereby doing much injury.

to fix boundaries, &c.; while our chief object is to obtain the features of the ground, and to lay down the courses of rivers and roads with sufficient accuracy for military purposes. Thus it appears that the business of a military surveyor is, in most points, quite distinct from that of a civil one; each adopts a method of proceeding, which he conceives to be best suited to his particular object.

I should not perhaps have touched at all on the subject of surveying as applicable to civil purposes, but for the consideration that a military man may have occasion to make a sketch without the aid of an instrument; and after the hints above given, he will not be entirely at a loss how to proceed.

A hasty, and therefore very imperfect, sketch is often made on actual service by the eye alone, without determining a triangle. For this no directions can very well be given. An intelligent officer soon finds out numerous little contrivances to assist his work. But I recommend that three or four points be laid down by intersections, even for the most trifling sketch; and I am satisfied that, in general, and when practicable, even time will be saved by this practice, while the sketch will be infinitely more accurate.

SECTION XVI.

A SELECTION OF USEFUL DEFINITIONS AND GEOMETRICAL PROBLEMS, WITH THE METHOD OF TRACING FIGURES ON THE GROUND.—MENSURATION OF PLANES.—HEIGHTS AND DISTANCES.—FINDING STATIONS, &c.

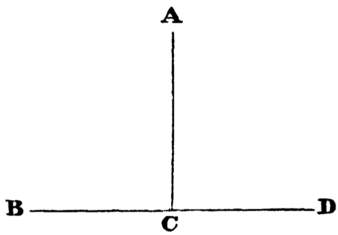
I BELIEVE we are indebted to the late Mr. Landman, of Woolwich Academy, for the earliest publication pointing out the methods of tracing geometrical figures on the ground. I shall only give a few of the most useful problems, which will be chiefly selected from the works of *Dalby*, *Landman*, *Hutton*, and others.

It is as easy to trace geometrical figures *on the ground* as upon paper; there is, however, some small difference in the mode of operation, because the instruments are different. A rod or chain is here used instead of a scale; the spade instead of a pencil; a cord fastened to two staves, and stretched between them instead of a ruler; the same cord, by fixing one of the staves in the ground, and keeping the other moveable, answers the purpose of a pair of compasses; and with these few instruments, every geometrical figure necessary in practice may be easily traced on the ground.

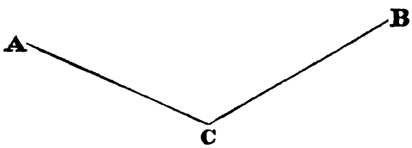
A SELECTION OF USEFUL DEFINITIONS IN GEOMETRY.

An angle is formed by the meeting of two straight lines at a point, C.

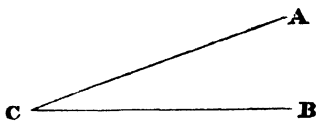
A right angle is formed by two lines, which are perpendicular to each other: thus, if AC is perpendicular to BD, each of the angles, ACB and ACD, is a right angle.



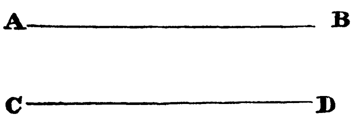
An obtuse angle, ACB, is greater than a right angle.



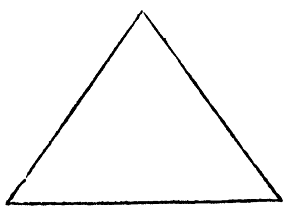
An acute angle, ACB, is less than a right angle.



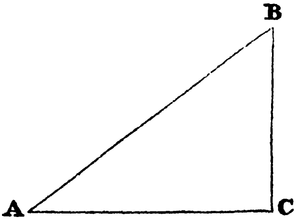
Parallel lines are those which have no inclination towards each other, or which are everywhere equi-distant, as AB and CD.



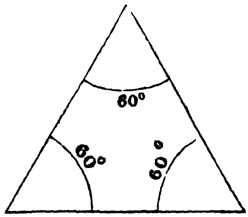
A plane triangle is a figure, bounded by three straight lines: it has, therefore, three sides, and three angles.



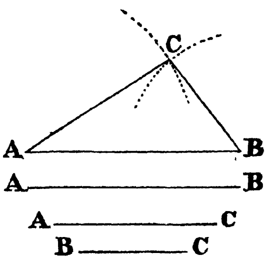
A right angled triangle is that which has one right angle, ACB.



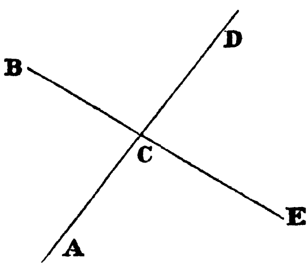
An equilateral triangle has three equal sides, and three equal angles.



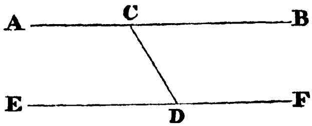
Three lines, A B, A C, and B C, being given, to form a triangle with them.—First, draw a line, and measure upon it the length of A B. Next take the length of A C in the compasses, and with one leg at A, sweep an arc or curve with the other leg. Then, take the length of B C in the compasses, and with one leg at B, describe a curve that will cut the one previously made from A. Lastly, join the point, C, where the arcs cut, to A and B—which completes the triangle.



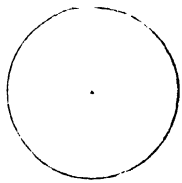
If one straight line cuts another, the opposite angles are equal: thus, the angle B C A is equal to the angle D C E, and the angle B C D is equal to A C E.



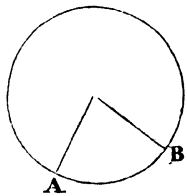
If a straight line be drawn so as to join two parallel lines, the alternate angles will be equal. Thus, A B and E F being parallel, the angle B C D is equal to E D C, and the angle A C D is equal to F D C.



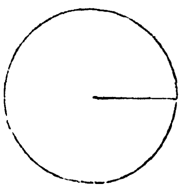
A *circle* is a plane, bounded by a curve line, called its circumference, which is every where equally distant from a point within it, called the centre.



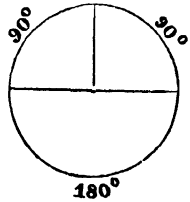
Any part of the circumference of a circle is called an *arc*. Thus, A B is an arc.



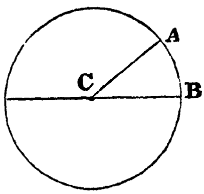
Any right line drawn from the centre of a circle to its circumference, is called a *radius*; and all radii of the same circle are equal.



The circumference of every circle is supposed to be divided into 360 equal parts, called *degrees*, each degree into 60 *minutes*, and each minute into 60 *seconds*. A quadrant, or fourth part of a circle, contains, therefore, 90°, being the fourth part of 360°; and a semicircle, consequently, 180°.



Angles are measured by supposing an arc of a circle, of which the angular point is the centre, this arc being considered as a portion of the circumference. Thus, the measure of the angle, A C B, is the arc, A B, reckoned in degrees, minutes, seconds.

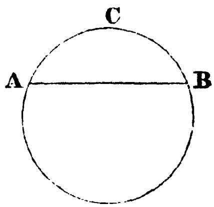


Right angles contain 90°, because their measure is a quadrant. The three angles of every triangle contain 180°, equal to two right angles. In a right angled triangle its two acute angles are together equal to 90°.

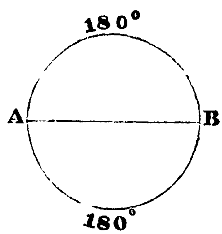
The *complement* of an angle or arc, is its difference from a right angle.

The *supplement* of an angle or arc, is its difference from a semicircle, or two right angles.

The chord of an arc is a right line joining the two extremities of that arc, Thus, A B is the chord of the arc, A C B.

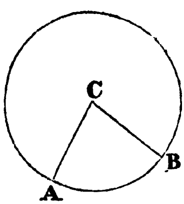


A *diameter* of a circle is a chord, AB, passing through its centre, and forming two semicircles, each containing 180°.

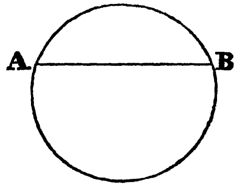


A *sector* is any part of a circle bounded by an arc, and two radii drawn to its extremities. Thus, if C be the centre, A C B is the sector.

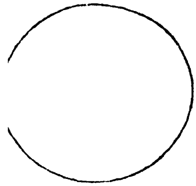
When the angle at C is a right angle, the sector becomes a quadrant.



A *segment* is any part of a circle cut off by a chord. Thus A B divides the circle into two segments.



A *tangent* is a right line touching the circumference without cutting off any part of the circle. Thus, A B is a tangent.



° is the mark of degrees.
′ . . . . minutes.
″ . . . . seconds.

Thus, 4° 10′ 12″ signify 4 degrees, 10 minutes, 12 seconds.

METHODS OF TRACING FIGURES ON THE GROUND.

1. *To draw upon the ground a straight line through two given points.*

Plant a picket or staff at each of the given points, then fix another between them in such a manner that, when the eye is placed at the edge of one staff, the edges of the other two may coincide with it. The line may then be prolonged by fixing up other staves. The accuracy of this operation depends greatly on fixing the staves upright, and not letting the eye be too near the staff from whence the observation is made.

2. *To walk in a straight line from a proposed point to a given object.*

Fix upon some point, as a bush or a stone, or any mark that you find to be in a line with your given object, and walk forward, keeping the two objects strictly in line; selecting a fresh mark when you come within 20 or 30 paces of the one upon which you have been moving. Observe that, to walk in a direct line, it is always necessary to have two objects constantly in view.

3. *To trace a line in the direction of two distant points.*

Let two persons separate to about 50 or 60 paces; then, by alternately motioning each other to move right or left, they soon get exactly into line with the distant objects; or, for greater accuracy, they may hold up staves.

In sketching ground, it is constantly necessary to get in line between two objects; if these are not very distant, a well-drilled soldier can always do so within a few paces (near enough for sketching purposes) by fronting one object exactly, and then facing to the right about; when, if he finds himself accurately fronting the other object, he will be tolerably well in line with them.

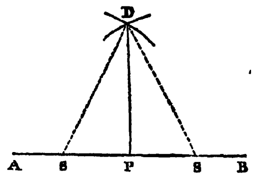
A right angle may also be formed very nearly by fronting an object, and then facing to the *right* or *left*.*

* There is no method of obtaining a right angle, preferable to that by aid of the sextant, as given in page 111.

I have found such little expedients very useful in practice, or I should not have ventured to mention them here, as some might consider them puerile.

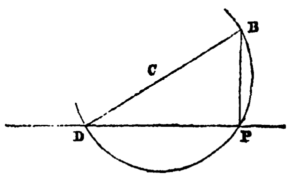
4. *At a given point,* P, *in a right line,* A B, *to raise a perpendicular,* P D, *to that line.*

On each side of P take equal distances, P S, P S, and about S, S, as centres, with the same radius, describe arcs intersecting each other at D; then draw P D for the perpendicular required.



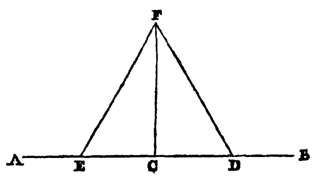
5. *When the given point,* P, *is near the end of the line.*

About any convenient point, C, as a centre, describe a circle through P, cutting the given line in D, draw D C B, then join B P, which will be the perpendicular required.

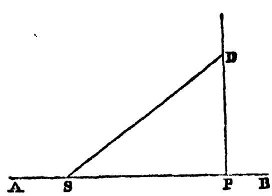


6. *To raise a perpendicular from a point,* C, *to the given line, A B, on the ground.*

Set off two points, E and D, equally distant from C; double a cord into two equal parts, and fasten the ends at E and D; take the middle of the cord in the direction of F, and draw tight; then will C F be the required perpendicular.

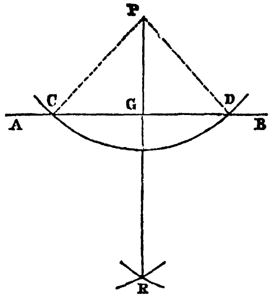


A perpendicular is easily raised on a given line, and consequently a right angle formed by means of the numbers 3, 4, and 5, or any multiples thereof. Thus, suppose a right angle is to be formed at the point, P, on the line, A B; take S P = 16, P D = 12, and S D = 20 feet; then P D will be perpendicular to A B.



The pocket-sextant offers the most accurate and expeditious method of raising or letting fall a perpendicular.—See page 112.

8. *From a given point,* P, *to let fall a perpendicular,* P G, *upon a given line,* A B.



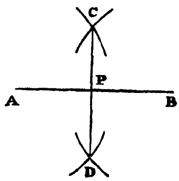
About P, as a centre, with any radius, P D, greater than the distance of P from A B, describe an arc, D C; and from D and C with a radius greater than half D C, describe arcs intersecting each other in R; join P R; then P G is the perpendicular required.

9. *To draw a line parallel to a given line on the ground.*

Raise two perpendiculars to the given line, and upon these set off equal distances; join the points, and the parallel line will be obtained.

A similar process will answer on paper; but a parallel ruler, or a small flat ruler, together with one of a triangular form which will be described further on, saves us the trouble.

10. *To bisect, or divide into two equal parts, a given line,* A B.



With any opening of the compasses greater than half the given line, about the extremities, A and B, as centres, describe arcs intersecting each other in C and D; then draw C D, and it will bisect A B in the point, P.

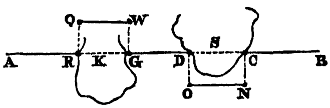
In this manner a line may be divided into 4, 8, 16, &c., equal parts:—thus, A P, B P, bisected, give 4 equal parts; and those again bisected would make 8; and so on.

11. The most expeditious method of finding the middle of a line on the ground is to measure equal distances from its

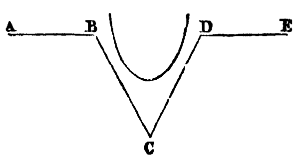
extremities. Thus, suppose A and B are the ends of the line, and that A D, B C (found by measuring from A to B), are each 164 feet; and the remaining part, D C, is 20 feet; then O, the middle of the line, will evidently be 10 feet from D or C.

12. In measuring lines or distances on the ground it sometimes may be necessary to take off-sets, when obstacles fall in the way.

Suppose A and B are the extremities of a line to be measured; and that K and S are pools of water or swamps. Having set up marks at R, G, D, C, in the line, A B, measure equal off-sets, C N, D O; and G W, R Q, at right angles to A B; then Q W and O N may be measured, instead of R G and D C.

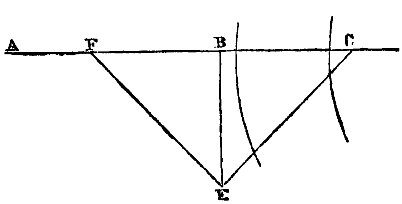


Perhaps a more convenient method is to measure on a line, making an angle of 60°, with the original direction, a distance sufficient to clear the obstacle, and to return to the line at the same angle; the distance, B D, is then equal to either of these measured lines.

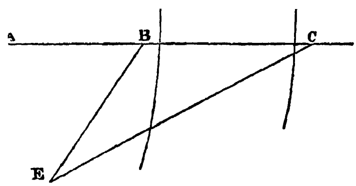


13. *To measure across a river.*

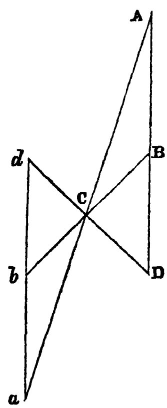
On the line, A B, take a point, F, making F B greater than the breadth of the river; set up a mark at E, forming a right angle at the point, B, and make B E about equal to F B: then, with any instrument for taking angles, make the angle, B E C, equal to B E F. Place a mark at C, in line with A B, and B C will be equal to F B.



Or, make B E to form any convenient angle with A B, and make the angle, BEC, equal to half the angle, A B E; then a mark being set up at C, in the prolongation of A B, it is evident that B C will be equal to B E.



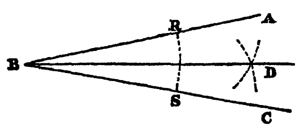
14. *To find the distance to any inaccessible point without an instrument for measuring angles.*



A is any inaccessible point whose distance from B is sought. Produce AB, to any point, D, draw D*d*, in any direction, and find C, the point bisecting it; join B C, and produce it to *b*, C *b* being equal to B C; join *d b*, and produce that line to *a*, meeting A C prolonged; then *a b* = A B and *a d* = A D.

15. *To bisect a given right-lined angle,* A B C.

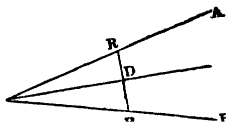
With any convenient radius, B S, about the angular point, B, as a centre, describe an arc, S R; and from the centres, S R, with any radius longer than half the distance between those points, describe two other arcs, intersecting one another in D; then the line joining B and D will bisect the angle, A B C, and the arc, S R.



By such bisections an angle, or its corresponding arc, may be divided into 2, 4, 8, &c., equal parts. A quadrant, or an angle of 90°, may thus by divided or subdivided, until each arc subtends an angle of only a few minutes. Such a division is readily performed if the radius is 5 or 6 inches; and will be found convenient for measuring the degrees of an angle, when the usual instruments for that purpose are not at hand.

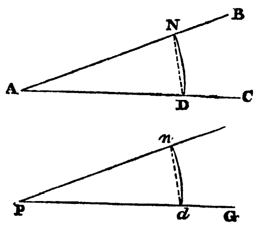
16. *To bisect an angle,* A C B, *on the ground.*

Measure equal distances, C R, C R, from the angular point, C: then D, the middle of the cross distance, RR, gives the direction of the line, C D, which bisects the angle.



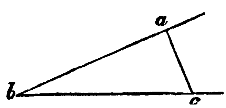
17. *At a given point,* P, *in a right line,* P G, *to make an angle* *n* P G, *equal to a given right-lined angle,* B A C.

About A and P, with the same radius, describe arcs, D N and *d n;* take *d n* equal to D N, and draw P *n;* then the angle, *n* P *d,* is equal to the angle, N A D or B A C.



18. *On the ground.*

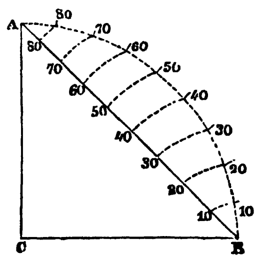
Set off any number of equal parts from B to C, and from B to A, and with the same parts measure A C; describe on the ground with these three lengths a triangle, *a b c,* and the angle *a b c,* will be equal to the angle A B C.



When it is proposed to make an angle which shall contain a given number of degrees, &c., a *protractor, line of chords,* or a sector will be necessary.

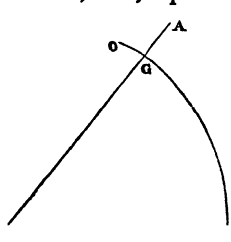
The common protractor is a semicircular instrument for measuring and laying down angles. The arc or limb is divided into 180 equal parts or degrees; and when its centre is placed over the intersection of two lines, the number of degrees in the angle is shown by the intercepted arc on the divided edge of the instrument. A protractor for the same purpose is frequently cut on the common plain scales, the centre being on one edge and the graduations on the other. This is the protractor mentioned at page 4.

A line of chords is made by transferring the divisions on the arc of a quadrant to its chord. Thus, suppose A C B is a quadrant, and the right line, B A, the chord of its arc. Let this arc be divided into 90 equal parts or degrees: then, if one foot of a pair of compasses be kept on the point, B, and arcs successively described with the other from each of the 90 divisions on the arc to meet B A, those arcs will divide it into a line of chords.



19. *To measure an angle with the line of chords.*

Suppose the angle, A C B: With the radius, C D, equal to the extent of 60 degrees on the line of chords, about the angular point, C, as a centre, describe the arc, D G; then the extent from D to G measured on the line of chords, gives the number of degrees, &c., contained in the angle: which in this example is about 51°.



Hence the method of laying down an angle which shall contain a proposed number of degrees, is obvious. Suppose, for example, it is required to make the angle, A C B, of 40 degrees: C B being a given line. With C D, the chord of 60 degrees, describe an arc, D O, as before; then 40 degrees, taken on the same line of chords, will extend from D to the point, G, in the arc, through which the line, C A, must be drawn, to form the required angle.

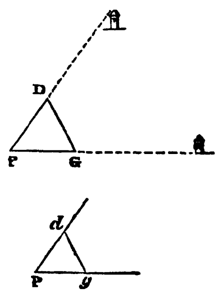
When the angles are greater than 90 degrees, measure or lay them off at twice. Or produce one side, so as to form two angles at the angular point, and then measure the supplement to 180 degrees.

The chord of 60 degrees is taken for the radius, because the sum of the angles of a triangle being 180 degrees, each angle of an equilateral triangle must therefore contain 60 degrees.

A line of chords is marked on the plain scale, furnished in a case of mathematical instruments.

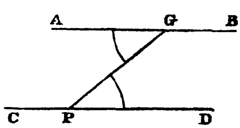
20. *To determine nearly the angle formed by a point, and two distant objects.*

To ascertain the angle, D P G, formed by two distant objects and an angular point, P, measure equal distances, P D, P G, and the cross distance, D G; then construct a triangle, *d p g*, on paper, similar to D P G, and measure the angle, *p*, with a protractor or the chords. Thus, if P D, P G, are each 30 feet, and D G = 28½ feet, the triangle, *d p g*, constructed with 30, 30, 28½ equal parts from any scale, will give the angle, *p* (or P), = 56¾ degrees nearly.



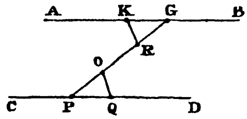
21. *Through a given point,* P, *to draw a line,* C D, *parallel to a given line,* A B.

From P draw P G, in any direction to meet the given line, A B; then make the angle, G P D, equal to the angle, A G P (17); and P D will be parallel to A B: because the alternate angles, A G P, G P D, are equal.



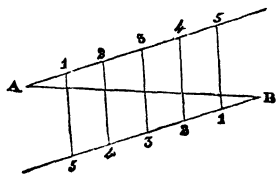
22. *To trace the parallel,* C D, *on the ground.*

Fix upon any convenient point, G in A B, and measure an isosceles triangle, R G K; then, at the point, P, lay down the triangle, O P Q, equal to R G K; and P Q will be parallel to G K.



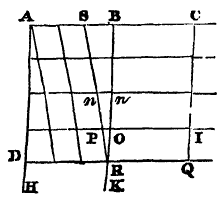
23. *To divide a given line,* A B, *into a proposed number of equal parts; suppose five.*

From the extremities, A and B, draw two lines, parallel to each other, forming any convenient angle with A B; on these lines set off five equal parts, of any length; join the opposite points of division; and A B will be divided into five equal parts.



24. Diagonal scales, which are constantly used, are thus constructed. Suppose a scale to 12ths of a line, A B, is required.

Having divided A B into three equal parts, draw two parallel lines, A H, B K, making any convenient angle with A B; on these lines take four equal distances, suppose from A to D, and from B to R; and through the points of division draw four lines, parallel to A B; next divide D R into three equal parts; then, if the points of division, in A B and D R, are joined diagonally, the scale is constructed.



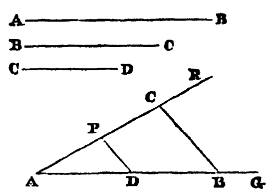
For by similar triangles, R B : B S :: R O : O P; therefore, R O being $\frac{1}{4}$ of R B, O P will be $\frac{1}{4}$ of B S, or $\frac{1}{4}$ of $\frac{1}{3}$ (or $\frac{1}{12}$) of B A; and the next division, *n n*, is $\frac{2}{12}$, &c.

If Q R = C B = B A is the scale of a *foot,* O P is an *inch,* *n n* = 2 inches, I P = 13 *inches,* &c. But if we divide A B into

4 equal parts, only 3 must be taken on A H and B K to make 12ths of A B (because $4 \times 3 = 12$).

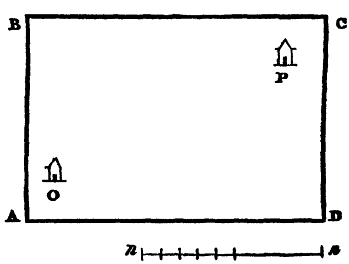
Generally, resolve the number to which the divisions are to be extended into two factors; then divide the given line (A B) into as many equal parts as there are units in one factor, and take as many equal parts on the other lines (A H, B K) as there are units in the other. Thus, if A B is divided into 3 equal parts, and 5 are taken on A H, B K; or if A B is divided into 5, and 3 are taken on A H, B H, in either case the scale gives 15ths of A B. On the common plain scales with mathematical instruments the equal parts on each line are 10, which give the divisions in 100ths.

25. *To find a fourth proportional to three given lines,* A B, B C, C D.



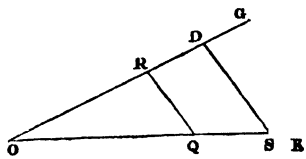
Draw two lines, A G, A R, forming any convenient angle at A, make A B = A B, A C = B C, and join B C; then take A D = C D, and draw D P parallel to B C. By similar triangles, A B : A C :: A D : A P, the 4th proportional required.

26. This Problem is of very extensive use in the reduction of scales, plans, and maps. We shall subjoin examples.



If A B C D be the plan of a country, and suppose the distance between the objects, O, P, is 1700 paces of a horse, at $2\frac{3}{4}$ feet each; it is required to make a scale of yards to the plan.

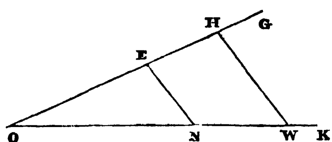
$$\frac{2\frac{3}{4} \times 1700}{3} = 1558 \text{ yards.}$$

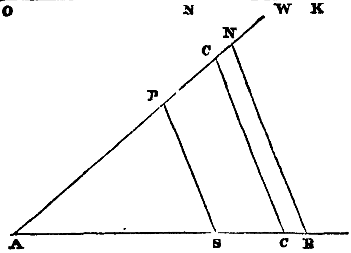


Having drawn two indefinite lines, O K, O G, forming any angle at O, make O S equal to the distance, O P; and from any scale of equal parts, set off O D = 1558, and O R = 1000; join D S, and parallel to it draw R Q, then O Q is a scale of 1000 *yards*. This divided and subdivided is the scale, *n n*, in which each of the least divisions is 100 *yards*.

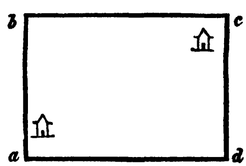
Or, without the construction, thus: the distance, O P, measured on a scale is 15·3 *inches*. Then, as 1558 : 1·53 :: 1000 : 0·98 *of an inch*, the length of *n n* the scale of 1000 *yards*.

27. Let the plan in the last example be reduced to a scale of 1 *inch to a mile*.





On the indefinite lines, O K, O G (as in the last example), set off O E = 1000, and O H = 1760 (the yards in a mile) from any convenient scale of equal parts; and make O N = the scale, *n n*; join E N, and parallel to it draw H W; then O W is the scale of a mile to the plan, A B C D.

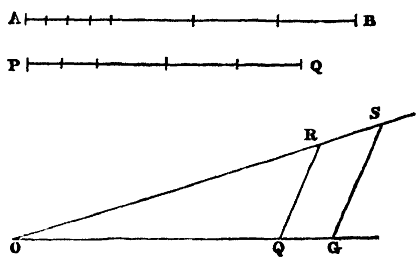


Now, with A C = O W, and C C = 1 *inch* (the two scales) make the isoceles triangle, A C C; then because any two corresponding distances on the plan must be in the same proportion as the two scales, if A R be made equal to the length of the plan, A B C D, and A S = A B its breadth, R N and S P (which are parallel to C C) will be the length and breadth of the reduced plan, *a b c d*.

28. Suppose a map is laid down to the scale, A B, of 4000 *toises;* and let it be required to adapt a scale (P K) of *English miles* (4 for example) to the same map.

The toise is $= 2{\cdot}1315$ yards. Therefore

$$\frac{2{\cdot}1315 \times 4000}{1760} = 4{\cdot}84 \textit{ miles} \text{ nearly, the scale, A B.}$$

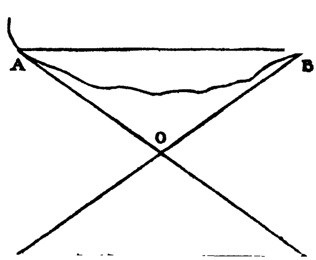


On two indefinite lines, O S, O G, making any angle at O, set off O S $= 4{\cdot}84$, and O R $= 4$, from any convenient scale of equal parts; make O G $=$ the scale, A B; join S G, and draw R Q parallel thereto; then Q O (P Q) is a scale of 4 miles.

Or thus:—The length of the scale, A B, is $1{\cdot}73$ *inches:* therefore, as $4{\cdot}84$ *m.* : $1{\cdot}73$ *in.* :: 4 *m.* : $1{\cdot}43$ *in.*, the length of the 4 mile scale, P Q.

And the map, or any part of it, may be enlarged or diminished to a proposed scale, after the manner seen in 26. For we can suppose A B C D to be a given part of a large plan.

29. *To find the length of the line,* A B, *accessible only at both ends.*

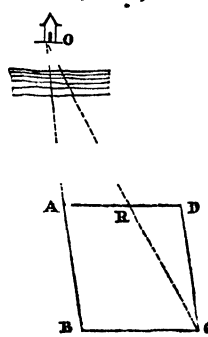


Having fixed on some convenient point, O, measure B O and AO; and prolong those lines till O C = O B, and O D = O A; then the distance between the points, D and C, will be equal to A B.

For the sides of the triangles, C O D, B O A, about the equal angles at O are respectively equal, therefore the third sides, C D, B A, will also be equal.

30. To find the distance of an inaccessible object, O, by means of a rhombus.

With a line or measuring-tape, whose length is equal to the side of the intended rhombus, lay down one side, B A, in the direction, B O, and let B C, another side, be in any convenient direction: fasten two ends of two of those lines at C and A; then the other ends (at D) being kept together, and the lines stretched on the ground, those lines, A C, C D, will form the other two sides of the rhombus. Set up a mark at R, where OC, AD, intersect; and measure R D; then the sides of the triangles, R D C, C B O, being respectively parallel, the triangles will be similar: hence, R D : D C :: C B : B O.



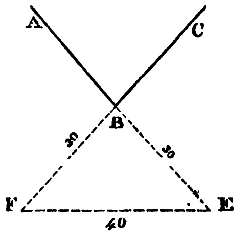
Suppose the side of the rhombus is 100 feet, and R D = 11 *ft.* 7 *in.*—then, $11\frac{7}{12}$: 100 :: 100 : 863 *feet nearly* = B O.

If the ground be nearly level, a rhombus, whose side is 100 feet will determine distances to the extent of 300 yards within a very few feet of the truth.

* An easy method of finding the distance of an inaccessible object, as an enemy's battery, &c., with an instrument, is to go off at an angle of 90°, and continue in that direction until you bring the object and your first station under an angle of 63° 2 ′ —the distance measured from your first station is equal to half the distance of the object from your first station. See the table, page 108, also the problem, page 111.

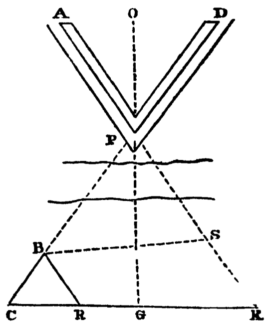
31. *To measure from the outside an angle,* A B C, *formed by two walls,* A B, C B.

Lay off 30 feet from B to E in the direction A B, and plant a staff at E; set off the same measure from B to F in the direction B C, and measure F E, and you may obtain the measure of your angle, either by laying it down on paper, or by calculation.



32. *To bisect an inaccessible angle.*

Let it be required to determine the direction of the capital, O P, of a bastion. At any points, B, S, in the directions of the faces, D P, A P, set up two marks; and from B trace B R, parallel to P S; measure equal distances, B C, B R, and mark the point, K, in the direction, C R; then find G, the middle of C K; and the prolongation of G P will bisect the angle of A P D.



Hence, if we measure C B, C R, C K, the distances, C P, K P, are found by similar triangles. For C R : C B :: C K : C P. And a perpendicular from B on C R will give the distance, G P, at another proportion.

MENSURATION OF PLANES.

The area of any plane figure is the measure of the space contained within its extremes or bounds.

This area, or the content of the plane figure, is estimated by the number of little squares that may be contained in it; the side of those little measuring squares being an inch, or a foot, or a yard, or any other fixed quantity. And hence the area or content is said to be so many square inches, or square feet, or square yards, &c.

33. Thus, if the figure to be measured be the four-sided one, A B C D, which is termed a rectangle (its four angles being right ones), and the little square, E, whose side is one inch, be the measuring unit proposed: then as often as the said little square is contained in the rectangle, so many square inches the rectangle is said to contain — which in the present case is 12.

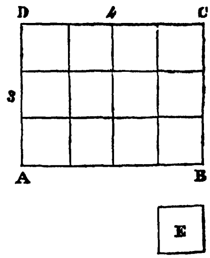


Table of Square Measure.

144	Square Inches *make*	1 Square Foot....	*Ft.*
9	Square Feet.......	1 Square Yard....	*Yd.*
30¼	Square Yards	1 Square Pole	*Pole.*
40	Square Poles......	1 Rood	*Rd.*
4	Roods	1 Acre...........	*Acr.*

Sq. In.		*Sq. Ft.*								
144	=	1		*Sq. Yd.*						
1296	=	9	=	1		*Sq. Pole.*				
39204	=	272¼	=	30¼	=	1		*Rd.*		
1568160	=	10890	=	1210	=	40	=	1		*Acr.*
6272640	=	43560	=	4840	=	160	=	4	=	1

34. *To find the area of any parallelogram (figure with four sides), whether it be a square, a rectangle, a rhombus, or a rhomboid.*

Multiply the length, taken in inches, feet, yards, &c., by the perpendicular height, and the product will be the area.

EXAMPLE.

To find the area of a parallelogram, the length being 12·25, *and breadth or height* 8·5.

$$\begin{array}{r} 12{\cdot}25 \ \textit{length.} \\ 8{\cdot}5 \ \textit{breadth.} \\ \hline 6125 \\ 9800 \\ \hline 104{\cdot}125 \ \textit{area.} \end{array}$$

35. *To find the area of a triangle.*

Multiply the length of the base by the perpendicular height, and take half the product for the area. Or multiply one of these dimensions by half the other.

36. *To find the area of a trapezoid (a four-sided figure, having two of its sides parallel).*

Add together the two parallel sides; then multiply their sum by the perpendicular breadth, or the distance between them; and take half the product for the area.

EXAMPLE.

In a trapezoid, the parallel sides are 750 and 1225, and the perpendicular distance between them 1540 links: to find the area.

$$\begin{array}{l} 1225 \\ 750 \\ \hline 1975 \times 770 = 1520750 \text{ square links} = 15 \text{ acr. } 33 \text{ per.} \end{array}$$

36*. *To find the area of any trapezium (a figure of four sides, no two of which are parallel).*

Divide the trapezium into two triangles by a diagonal; then find the areas of these triangles, and add them together.

An officer may have occasion to measure and compute the content of pieces of ground, fields, &c.; for such a purpose, Gunter's chain is very convenient. Its length is 4 poles, or 22 yards, or 66 feet. It is divided into 100 links; and the length of each link is therefore $\frac{22}{100}$ of a yard, or $\frac{66}{100}$ of a foot, or 7·92 inches.

Land is estimated in acres, roods, and perches. An acre is equal to 10 square chains, or as much as 10 chains in length, and 1 chain in breadth. Or, in yards, it is $220 \times 22 = 4840$ square yards. Or, in poles, it is $40 \times 4 = 160$ square poles. Or, in links, it is $1000 \times 100 = 100{,}000$ square links: these being all the same quantity.

Also, an acre is divided into 4 parts, called roods, and a rood into 40 parts, called perches, which are square poles — or the square of a pole of $5\frac{1}{2}$ yards long — or the square of $\frac{1}{4}$ of a chain — or of 25 links, which is 625 square links. So that the divisions of land-measure will be thus:—

625 square links = 1 pole or perch.
40 perches.... = 1 rood.
4 roods...... = 1 acre.

The lengths of lines, measured with a chain, are best set down in links as integers, every chain in length being 100 links; and not in chains and decimals. Therefore, after the content is found, it will be in square links; then cut off five of the figures on the right hand for decimals, and the rest will be acres. These decimals are then multiplied by 4 for roods, and the decimals of these again by 40 for perches.

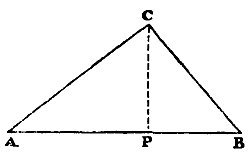
Example.

Suppose the length of a rectangular piece of ground be 792 links, and its breadth 385; to find the area in acres, roods, and perches.

792	3·04920
385	4
3960	·19680
6336	40
2376	7·87200
3 04920	

Ans. 3 *acres,* 0 *roods,* 7 *perches.*

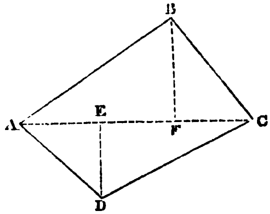
38. *To survey a triangular field,* A B C. *By the chain.*



Having set up marks at the corners, which is to be done in all cases where there are not sufficient marks existing, measure with the chain from A to P, where a perpendicular would fall from the angle, C, and set up a mark at P, noting down the distance, A P. Then complete the distance, A B, by measuring from P to B. Having set down this measure, return to P, and measure the perpendicular, P C. And thus, having the base and perpendicular, the area is easily found by multiplying the length, A B by P C, and taking half the product. Or, the figure may be constructed by measuring an angle, as C A B, and the two sides, A C and A B. Or, measure one side, A B, and the angles at

A and B. By either of these ways, the figure is easily planned; then, by measuring the perpendicular, C P, on the plan, and multiplying it by half A B, the content is found.

39. *To measure a four-sided field,* A B C D.



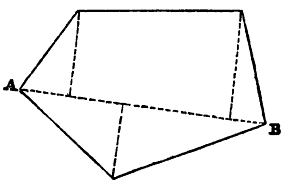
Divide it into two triangles by a diagonal, A C, and find the content of each, as in the last problem.

To take the plan of such a field, measure the four sides, and one of the angles, as A B C; when the figure is easily constructed. Or, measure the diagonal, A C, and the four angles, B A C, C A D, B C A, and A C D.

40. *To measure any field by the chain only.*

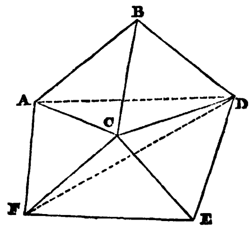
Divide it into triangles and trapeziums, by running lines across from corner to corner: then calculate the content of each triangle and trapezium separately.

To make the plan of any field, measure a base line, A B, across it, and having placed marks — such as a stick, with a bit of white paper on it — at each corner, as also similar marks to show the base line; put a mark at every point on the line, at which a perpendicular from a corner of the field will fall; which point is best determined by means of the pocket-sextant (page 111); then measure these perpendiculars as off-sets. A diagram of the field, drawn by the eye, is better to note the measurements upon than a field-book.



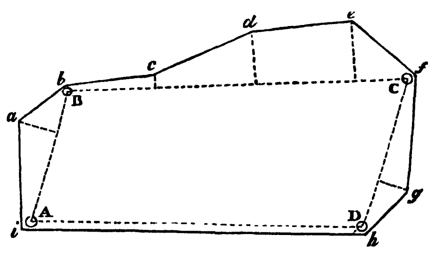
41. *To take the plan of any field with an instrument.*

Plant the instrument at any point, C, near the middle of the field, and having placed marks at every angle of it, measure the distances from the instrument to each corner; as also the angles, A C B, B C D, D C E, &c., when a plan can be easily formed of it. Or, the instrument may be placed at one of the corners, from whence the others are visible, as D; then measure the angles, B D A, A D F, and F D E (formed by the dotted lines); then measure D E, D F, D A, and B D. Note the measures of the angles and lines on a rough figure drawn to resemble the true one.



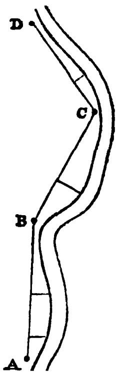
42. *If the field have irregular lines bounding it.*

Fix upon three or more stations, as A, B, C, D, and measure the angles, A B C, B C D, A D C, and BAD; then measure the sides, B C, C D, A D, and A B: and while doing this, take off-sets to *a*, *b*, *c*, *d*, *e*, &c.



The imaginary figure, A, B, C, D, may be formed outside the field or piece of ground, if more convenient.

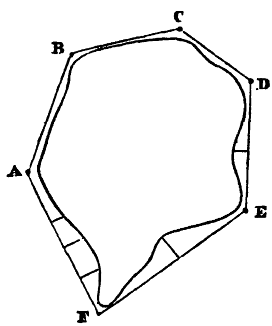
43. *To obtain the plan of a river.*



Place marks at its principal bends, A B, C, D, and with a theodolite or surveying compsss take the bearings of the station-lines, A B, B C, C D, &c.; and when measuring these lines take off-sets to all the smaller bends, as shown in the diagram.

The plan may either be protracted in the field, or the bearings and measurements entered in a field-book.

44. *To take the plan of a wood, a lake, or marsh, &c.*

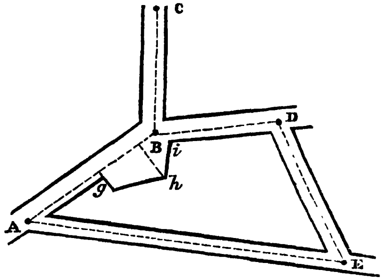


Place marks, A, B, C, &c., so as to form the most convenient station-lines, A B, B C, &c., all round the wood or marsh; then with a surveying compass take the bearings of A B, B C, C D, &c., going all round, measuring and taking off-sets as you proceed. If the survey be of a marsh or lake, *check* bearings should be taken across it, as from A and E to D, &c.; which will ensure greater accuracy, and cause the work to close (as it is termed) with proper exactness.

The method, recommended in Section II., of surveying and protracting, so as at once to obtain a correct plan, is well suited to objects of this kind.

45. *To take the plan of a town.*

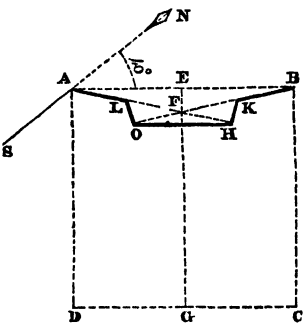
This is done precisely in the manner pointed out in Section VI., for surveying a road. Thus, suppose the annexed diagram to represent a town, and the point, A, from which we can look



down two streets, A B and A E, is selected for commencing the survey. We will suppose a theodolite to be used, and that the survey is to be made by the *needle* (page 28). First take the bearing of B, then that of E; measure A B, taking the necessary off-sets for the width of the street (page 30). The points, *g*, *h*, *i*, where the street opens into a wide space, are also determined by off-sets taken perpendicularly to the chain line. At B the bearings of B C and B D are taken, and their distances measured. At D take the bearing of E, when, if the length of the line, A E, on the survey, being laid down or protracted, agrees with the measured distance, a proof is afforded that the work is accurate.

When using a theodolite the back-angle method (page 36) is preferable to depending on the needle, which is liable to be affected by local attraction. Bandrols or staves, used as marks for the stations, will require to be held by an assistant, as they cannot be planted in streets. When a compass is used for the survey, these may be dispensed with, as corners, door-posts, &c., will serve as marks.

46. *To trace out a field-work with the aid of a surveying compass.*



We will suppose the required field-work to be a square-bastioned fort. Having fixed the direction of one exterior side, AB, mark its length, say 200 yards, and trace the square, A B C D; thus, at A take the bearing of B, which we will suppose to be 40°, E., the angle, NAB (N S representing the magnetic needle). Add 90°, and we have 130° E. (page 7) for the direction, A D, of a line, at right angles with AB. Cause an assistant to hold a staff nearly in the required direction, A D, which he is to move by signal until his staff is found to bear exactly 130° E.; it is then to be fixed in the ground. Proceed to B, and by the same process plant a staff which shall bear 130° S. E., the direction of C; make A D and B C each equal to A B, and the four points of the square are determined.

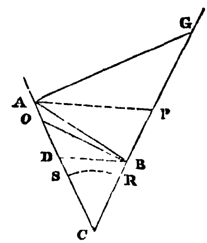
Next bisect A B and D C, and the direction, E F, of the *perpendicular* is obtained. Take E F, equal to $\frac{1}{8}$ of A B (the usual proportion for a square), and the *lines of defence*, A H and O B, are then easily traced. On these lay off A L and B K, equal to the proposed length for the faces of the *bastions;* and from L and K let fall perpendiculars to A H and B O, respectively, for the *flanks;* join O H, the *curtain*, and one *front* of the work is traced.

APPLICATION OF TRIGONOMETRY TO MEASURING HEIGHTS AND DISTANCES.

The instrument proper for measuring horizontal and vertical angles, in common trigonometrical operations, is a theodolite, furnished with one or two telescopes, and a vertical arc; a general description of which will be found at page 21, and the method of further adjusting it at page 139.

But, after all the care that may have been bestowed in correcting the line of collimation, telescope-level, &c., it seldom happens that the elevations or depressions shown by the instrument are correct. It is therefore always advisable to determine the *error*, or how much the elevations or depressions are too great or too little. This may be done in the following manner:—

47. Let C be the centre of the earth, S R an arc on its surface, A the place of the telescope when the theodolite stands in the vertical line C A, B the place of the telescope when it stands in the vertical line C B, A G (perpendicular to A C) the horizontal line at A drawn to meet C G, and B O (at right angles to B C) the horizontal line at B.



Then, if the telescope at B be directed to a mark or object at A, the elevation of that object above the horizontal line, B O, is the angle, O B A; and when the telescope is at A, and directed to an object at B, its depression below the horizon, A G, will be the angle, G A B.

Let S D = R B, and R P = S A. Then because the triangles, A P C, D B C, are isosceles, and the angles, C A G, C B O, right ones, the angle C A P + angle P A G = a right angle; but the angle C A P + half the angle A C P, also make a right angle; therefore the angle, P A G, or its equal, D B O, is equal to half the angle, C.

Now the depression or angle, G A B = G A P + P A B (or A B D); or G A B = P A G + D B O + O B A; but P A G + D B O = angle C. Therefore the depression, G A B = angle C + *elev.* O B A; or *depr.* G A B + *elev.* O B A = angle C + twice the *elev.* O B A. Therefore the elevation and depression together, lessened by the angle, C, is equal to twice the elevation; consequently, *half the difference between the sum of the elevation and depression, and the angle,* C, *is the elevation.*

Now, whatever be the error in elevation or depression, their *sum* will be constant; for one is always diminished by the same quantity that the other is augmented: hence the preceding rule gives the *true elevation*, except the angle, C, be greater than the elevation or depression together, in which case the said *half difference* is the *true depression* of the highest of the two points or objects, A, B.

And when the observations are both elevations, or both depressions, their *difference* is constant, and *half the difference between the angle,* C, *and that constant difference, will be the true elevation of the highest of the two points,* A, B, *if the angle,* C, *be the less, but equal to the true depression of that highest point or object when it is the greater.*

Should both the reciprocal observations be depressions (or both elevations), and equal to each other, the vertical heights, S A and R B, are equal; and the true depression will be half the angle, C.

EXAMPLE.

The following observations were made with a theodolite, for determining the error in the vertical angles taken with that instrument.

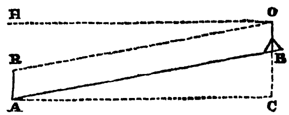
Two marks, A and B, were set up exactly at the same height above the ground as the height of the telescope; and at A the depression of B, or the angle, G A B, was 24′; and at B the elevation of A, or the angle, O B A, = 12′. The distance of the stations or arc, S R, was 2600 yards, which, allowing $69\frac{1}{6}$ miles to a degree, gives 1′ ·28 of a degree nearly, the angle, C.

Then, $\frac{24' + 12' - 1'\cdot 28}{2} = 17'\cdot 36$, or about $17\frac{1}{4}'$, the true elevation or angle, O B A; consequently, $17\frac{1}{4}' - 12' = 5\frac{1}{4}'$ is the *error*, or what the altitudes shown by the instrument were too little, or the depressions too great.

A distance of 600 or 700 yards, however, is sufficient for trying a common theodolite; in which case the angle, C, may be neglected, and the verticals, S A and R B, considered as parallels: the expressions then become more simple. Thus, if one observation be an elevation = 17′, and the other a depression = 13′, then *half their sum* = 15′ is the true elevation or depression; and 17′ — 15′ = 2′ is what the instrument gives elevations too great. If both are elevations, or both depressions, *half the difference* is the true elevation of one station, and the true depression of the other.

48. A base for trigonometrical operations is sometimes measured on sloping ground, it must then be reduced to the corresponding horizontal line, if horizontal angles at its extremities are taken with a theodolite.

Suppose A B is a base of 300 yards, O B a theodolite, and let the height of the staff, A R, be equal to O B, the height of the instrument; also suppose H O R, the angle of depression of the top, R, below the horizontal line, H O, is 5°; then, if O C is perpendicular to H O, the line, A C, parallel to H O, will be the horizontal base, corresponding to the measured base, A B.



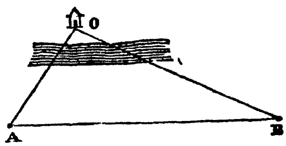
Now, the angles, H O R, B A C, being equal, we have

As radius	log.	10·000000
To A B 300	log.	2·477121
So is *cosine* of 5° (angle, B A C)	log.	9·998344
To A C, 298·9	log.	2·475465

The difference of A B and A C is only 1·1 yards. Therefore a reduction of this kind seems unnecessary when the measured base is inclined to the horizon in a small angle, except the operation is intended to produce a very accurate result.

49. *To find the distances,* A O, B O, *from the stations,* A *and* B, *to the inaccessible object,* O.

A base, A B, was measured of 730 feet, the ground being nearly level; and having set up marks at A and B, the horizontal angles at those stations, taken with the theodolite,



were $\begin{cases} A = 57° \ 12' \\ B = 24 \ \ 45, \end{cases}$ whence the distances, A O, B O, are required.

The angle at O, or supplement of the angles, A and B, is 98° 3′. And the *calculation* will be,

As sine angle O, 98° 3′ ...... log. .	9·995699	
	0·004301	arith. comp.
To AB, 730 .... log. .	2·863323	
So is sine of angle A, 57° 12′ log. .	9·924572	
To BO, 619·7 feet .... log. .	2·792196	

And,

As sine of angle O, 98° 3′ .... log. .	9·995699	
	0·004301	arith. comp.
To AB, 730 .... log. .	2·863323	
So is sine of angle B, 24° 45′ log. .	9·621861	
To AO, 308·6 feet .... log.	2·489485	

By *construction.* — Take A B = 730 from any convenient scale of equal parts; and by means of a *protractor,* make the angle at A = 57° 12′, and the angle at B = 24° 45′: then the distances, AO and BO, may be measured by the same scale from which A B was taken.

50. *Wanting to know the breadth* (DO) *of a river.*

A base, AB, of 400 yards was measured along the bank, and at the extremities, A and B, angles were taken to an object, O, on the opposite side.

Namely, $\begin{cases} \text{Angle O B A} = 37° \; 40′ \\ \text{Angle O A B} = 59 \;\; 15. \end{cases}$ Hence the breadth, O D, is required.

Calculation,—

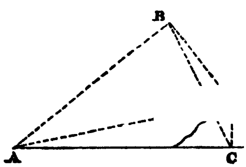
As *sine* of the angle BOA, 83° 5′ (the supplement of the angles B and A)	log.	9·996828
		0·003172 arith. comp.
Is to B A, 400	log.	2·602060
So is the *sine* of angle B, 37° 40′...	log.	9·786089
To A O	log.	2·391321
Then,		
As *sine* of angle ODA, 90°	log.	10·000000
Is to A O	log.	2·391321
So is *sine* of angle A, 59° 15′.....	log.	9·934199
To O D, 211·6 yards	log.	2·325520

Or O D may be ascertained by *construction.* Make B A = 400 from a scale of equal parts; and at the extremities, B and A, lay down the respective angles 37° 40′ and 59° 15′; then the perpendicular, O D, upon the base, B A, will be the breadth required. And its measure is 212 nearly.

51. *Wanting to know the distance* (A C) *of a hill from the station,* A, *and also the height* (O C).

A base, A B, of 298 yards was measured on ground nearly horizontal, and at the extremities, A and B, we observed the horizontal angles, BAO (or BAC) = 42° 17′, ABO (or ABC) = 79° 29′; and at A, the angle of elevation, OAC, was 4° 51′. Required the distance, AC, and height, CO.

Method of construction.—The three points, A, B, C, being supposed in a plane parallel to the horizon, and the plane of the instrument at A and B in that plane, the angles taken to the point, O, in the perpendicular, CO, will be the same as they would be if the telescope



was directed to the point, C, because the horizontal circle of the theodolite is not moved by elevating or depressing the telescope, Therefore, having made A B = 298, and the angle, B A C = 42° 17′, A B C = 79° 29′, and O A C = 4° 51′, raise the perpendicular, C O; then A C is the distance, and C O the height sought.

Calculation.—The angle, A C B, is 58° 14′, the supplement of the horizontal angles at A and B.

As *sine* of 58° 14′	log.	9·929521
		0·070479 arith. comp.
Is to AB, 298	log.	2·474216
So is *sine* of ABC, 79° 29′	log.	9·992643
To A C, 344·6	log.	2·537338

And for the height, C O,

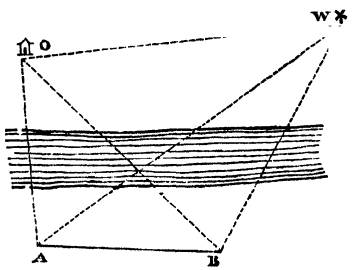
As radius	log.	10·000000
Is to *tangent* of angle O A C	log.	8·928658
So is A C, 344·6	log.	2·537338
To C O = 29·2	log.	1·465996

52. *To find the horizontal distance between the inaccessible objects,* O W.

A base, A B, of 670 yards, was measured on ground nearly horizontal; and at the extremities, A and B, the following angles were taken:—

At A, $\begin{cases} \text{B A W} = 40° \ 16' \\ \text{W A O} = 57 \ \ 40 \end{cases}$ At B, $\begin{cases} \text{A B O} = 42° \ 22' \\ \text{O B W} = 71 \ \ \ 7 \end{cases}$

By *construction.*—From any convenient scale of equal parts, make A B = 670, and lay down the respective horizontal angles at A and B; join O W, the points of meeting of the lines from A and B; and O W, measured on the scale from which A B was taken, will be 1170 yards nearly, the *horizontal* distance between the objects.



By *calculation*,—

$$\text{The angles of the triangle, A O B, are}\begin{cases} \text{A B O} = 42^\circ\ 22' \\ \text{O A B} = 97\ \ \ 56 \\ \text{A O B} = 39\ \ \ 42 \end{cases}$$

Whence A O will be found = 706·8 yards.

$$\text{And the angles of the triangle AWB are}\begin{cases} \text{B A W} = 40^\circ\ 16' \\ \text{A B W} = 113\ \ \ 29 \\ \text{A W B} = 26\ \ \ 15 \end{cases}$$

Will give A W = 1389·4 yards.

$$\text{Now in the triangle O A W we have}\begin{cases} \text{A W} = 1389 \cdot 4 \\ \text{A O} = 706 \cdot 8 \end{cases}$$

And the included angle O A W = 57° 40′

To find O W.

The distances, both by construction and calculation, are the horizontal ones.

Should O and W be objects elevated, as the tops of hills, their altitude may also be found by observing the respective angles of elevation from the stations A and B.

53. *To ascertain the height of a building.*

Measure a line, F E, from the foot of the building, so that the angle, C D A, may be neither too acute nor obtuse; thus, suppose E F = 130 feet, place your theodolite or sextant at D and measure the angle, A D C, = 34° 56′.

Then, as radius is to tangent 34° 56′, so is D C = E F = 130 feet to A C.

Which, by working the proportion, is found to be 90·8 feet or 90 feet 9·6 inches, to which adding 4 feet for D E, or its equal, C F (height of the instrument), the whole height is found to be 94 feet 9·6 inches.

Should the foot of a building be inaccessible, owing to the presence of a ditch or other obstacle, a base, F G, must be measured (see the fig., page 110), and two angles of elevation taken, viz., A C E and A D E; then in the triangle, A C D, one side, D C, and the angles are given to find C A; by means of which, and the angles of the triangle, A C E, the height, E A, is obtained, to which C G = E B the height of the instrument is to be added.

Observe. That the ground upon which the base is measured must be level, if an accurate result be expected.

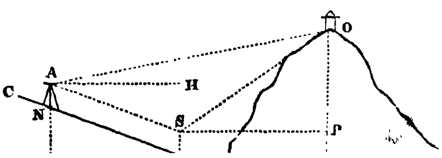
54. *To find the height and the distance of the object,* O, *on the top of a hill from the station,* B.

We measured a base, B N, of 642 yards, up the sloping ground, B C, directly from the object, O, the points, O, B, N, being in the same vertical plane; then, having set up a staff, B S, whose length was equal to the height of the theodolite, we found the angles of elevation and depression to be as follows:—

At the station, N, $\begin{cases} \text{object, O, elev. } 3^\circ\ 59' = \text{ang. O A H.} \\ \text{top of staff, S, depr. } 39' \text{ ang. H A S.} \end{cases}$

At the other station, B, the elev. of O $= 5^\circ\ 52' =$ ang. P S O.

Hence the horizontal distance, B R, the height, R O, and also G N, the height of the station, N above B, are required.



Method of construction. Draw R G indefinitely, to represent an horizontal line, and from any point, B, draw the slope, B C, making the angle, G B C, = 39′ (the angle, H A S); then, from a scale of equal parts, set off B N = 642, and B S perpendicular to B G, and equal to the height of the theodolite, N A;

let S A be parallel to B C, and equal to B N, and A G parallel to S B; also draw the horizontal lines, A H, S P; then if the angles, O S P, O A H, are made equal to 5° 52′, and 3° 59′, the angles of elevation respectively, and O R is perpendicular to G R, the figure will be constructed.

Calculation—

Angle O A H = 3° 59′
H A S = 39....its supplement 179° 21′ ang. A S P
Subtract 5 52 ang. O S P
Angle O A S = 4 38
173 29 ang. O S A

Therefore, the angles of the triangle, O A S, are

O S A = 173° 29′
O A S = 4 38
A O S = 1 53

As *sine* A O S, 1° 53′.........	log. .	8·516726
		1·483274
Is to A S, 642...............	log. .	2·807535
So is *sine* of O A S, 4° 38′.....	log. .	8·907297
To S O.....................	log. .	3·198106

Then,

As *sine* S P O, 90°............	log. .	10·000000
Is to S O..................	log. .	3·198106
So is *sine* O S P, 5° 52′........	log. .	9·009515
To the height O P, 161·3......	log. .	2·207621

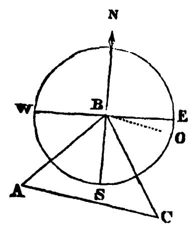
S O...................	log.	3·198106
5° 52′ *cosine*.............	log.	9·997719
Dist. SP = BR = 1569·7	log.	3·195825

As *sine* angle N G B, 90°......	log. .	10·000000
Is to N B, 642...............	log. .	2·807535
So is *sine* N B G, 39′..........	log. .	8·054781
To N G, 7·3 yards, nearly......	log. .	0·862316

And if S B (P R) the height of the theodolite, when standing on the ground, be added to O P, we shall have the height of O above the horizontal line, G R.

55. *In surveying with a prismatic compass (numbered as described at page 2) an object* C *bore* 146° 15′ E., *and when we had gone* 240 *yards in a direction bearing* 45° W., *the object bore* 101° 15′ E. *Required its distance from the stations* B *and* A.

Construction.—Let the circle, whose centre is B, respresent the compass; N., E., W., S., the north, east, west, and south points: draw B O, making the angle N B O = 101° 15′; B C, to make the angle N B C = 146° 15′; B A so as to make the angle S B A = 45°; also make B A = 240 from a scale of equal parts; then, if A C be drawn parallel to B O, C will be the place of the object.



Method of *calculation,*—

$$\text{In the triangle ABC} \begin{cases} \text{Angle ABC} = 78^\circ\ 45' \\ \text{ACB} = 45\ \ 0 \\ \text{BAC} = 56\ \ 15 \end{cases}$$

And the side B A = 240, whence A C = 332, and B C = 282 yards.

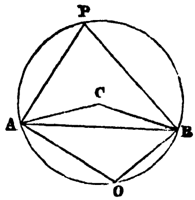
The method of finding your place on a map or plan by means of a compass, either when reconnoitring a country with the aid of the former, or when filling in the latter, has been described in Section IV. But it may happen that you have no compass, or that the variation of the needle is not exactly known; perhaps also a true meridian line may not have been laid down. In any one of these cases your position may be fixed by taking two angles with a theodolite or pocket-sextant to three or more objects, whose distances apart are known. Several ingenious problems have been devised in illustration of the cases that may arise from exercising this mode of finding your place; a few of which I shall present to my readers. They all depend, however, upon a single geometrical problem, namely, that by which we are enabled upon a given line to describe a segment of a circle, which shall contain a given angle. That this is necessary the following observations will show:—

Two objects can *only* be seen under the *same* angle, from places situated in the circumference of an imaginary circle, passing through those objects and the place of observation.

If the angle under which those objects appear be less than 90°, the place of observation will be somewhere in the arc bounding the greater segment, and the objects will be seen under the same angle from every part of that arc.

If the angle under which the objects are seen be more than 90°, the place of observation will be somewhere in the arc of the lesser segment, and those objects will be seen under the same angle from every part of the arc bounding that segment. Hence, from the situation of three known objects, we are enabled to determine the station-point with accuracy.

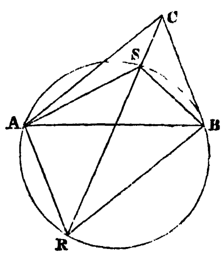
56. *On a given line,* A B, *to describe a segment of a circle, that shall contain a given angle.*



At the extremities, A, B, of the given line, make each of the angles, CAB, CBA, equal to the difference of the proposed angle and a right one; and with C A or C B describe a circle: then the segment, A P B, on the same side of A B as the centre, C, will contain the given angle when it is *less* than a right one; and the opposite segment, AOB, will contain it when it is *greater.*

57. *If* A, B, C, *be three objects, whose distances from each other are* A B = 4516, A C = 4809, B C = 3018 *yards: and suppose at the station* S, *we observe the angles* CSB = 117° 56′, B S A = 110° 12′; *it is required to find the distances from the station to the three objects.*

By construction. — If the triangle, A B C, be laid down with the three given distances, and segments of circles described upon any two sides to contain the angles they subtend, the intersection of the arcs will evidently be the station, whether it falls within or without the triangle. But the following method is rather more simple:—About A B describe a circle, so that the segment, A B S, shall contain the angle 110° 12′: make the angle B A R = 62° 4′ the supplement of 117° 56′ (C S B), join C R; and S, where it intersects the circle, is the station. For if A S, S B, B R, are drawn, the angle A S B is = 110° 12′ by construction; and R S B being equal to R A B (standing on the same arc), or 62° 4′, the angle C S B, which is its supplement, will be 117° 56′, the other observed angle.



Calculation.—The three sides 4516, 4809, 3018 give the angle A B C = 76° 28′.

Angle A B R (=A S R, the supplement of A S C)	=	48° 8′
B A R	=	62 4
A R B	=	69 48

These, with the side A B give B R = 4251·3.

The angle R B C = 48° 8′ + 76° 28′ = 124° 36′, which, with the two including sides, give R C B = 32° 47′, and C R B = 22° 37′.

Now S A B = S R B = 22° 37′; therefore all the angles of the triangles A S B, B S C are given: namely,—

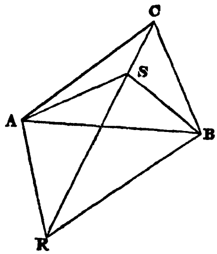
S A B =	22° 37′	S C B =	32° 47′
A S B =	110 12	C S B =	117 56
S B A =	47 11	S B C =	29 17

Whence the distances, S A, S B, S C, are found to be 3530, 1851, 1672 yards, respectively.

When the station is without the triangle (suppose at R), it is evident the circle must be described so that the outward segment, A R B, shall contain the whole observed angle, A R B; then, if the angles, A B S, B A S, be made respectively equal to the observed angles, A R C, B R C, and C R drawn through S, it will give the station, R.

If the whole observed angle, A R B, should be equal to the supplement of the angle, A C B, the circle will pass through the point, C, in which case the problem is indeterminate; for the angles standing on the chords, B C, A C, would be the same in all points of the arc, A R B.

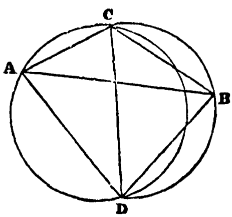
It appears from the preceding construction that it is not necessary to describe a circle. For example, if the station be within the triangle, then the angles, B A R, A B R, being made equal to the supplements of the observed angles, B S C, A S C, the intersection of A R and B R gives the point, R; then, if the angle, A B S, be made equal to the angle, A R C, B S will meet R C in S, the station. On the contrary, when the place of observation is without the triangle, the angles, A B S, B A S, are made equal to the observed angles, A R C, B R C, respectively; then C R being drawn through S and the angles, A B R, B A R, made equal to A S R, B S R, B R and A R will meet C R, in R the station.



In this latter case, however, when the point, S, falls near the object, C, the *construction* may give the point, R, considerably wide of the truth.

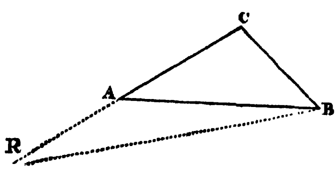
58. *Or by another method.*

Let A, C, B, be the three points, forming a triangle whose distances from each other are known, and that we want to determine the situation of a point, D. Observe the angle, A D C, C D B; and on A C describe the segment of a circle that will contain the angle, A D C; and on B C a segment to contain the angle, C D B; then will the point, D, where the two circles intersect, be the place of observation.



59. Case 2. *When the given place or station,* R, *is without the triangle, made by the three given objects,* A, B, C, *but in a line with one of the sides produced.*

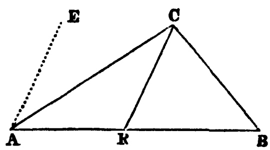
Measure the angle, A R B, then the problem may be easily solved, either by construction or calculation.



By construction. Subtract the measured angle, A R B, from the angle, C A B, and you obtain the angle, A B R; then at B, on the side B A, make the angle, A B R, and produce C A to meet B R at R, the station.

By calculation. In the triangle, A B R, the angle, R, is obtained by observation; the angle, B A R, is the supplement of the angle, C A B, to 180°; two angles of the triangle being thus known, the third is also known; we have, therefore, in the triangle, A R B, the side, A B, and all the angles to find A R and R B.

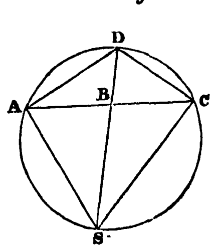
60. CASE 3. *When the station-point is in one of the sides of the given triangle.*



By construction. Measure the angle, C R B, and make the angle, B A E, equal to the observed angle; then draw C R parallel to E A, and R is the station-point required.

By calculation. Find the angle, B, in the triangle, A B C, then the angles, B and B R C, being known, we obtain R C B; and, consequently, as sine angle, B R C, is to B C, so is sin. angle, R C B, to B R.

61. CASE 4. *When the three given places are in a straight line.*



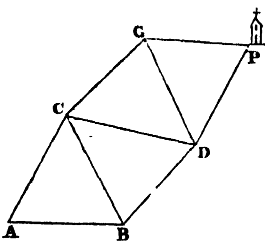
By construction. A, B, C, are three points in a straight line, whose distances from each other are known. Observe the angles, A S B, C S B; then on A C describe a circle, so that the segment, A S C, shall contain an angle equal to the whole angle, A S C. Make the angle, C A D = C S B, and A C D = B S A; and from the point of intersection, D, draw a line through B to meet the circle at S, which will fix S, the station.

By calculation. In the triangle, A D C, we have given, the side A C, and all the angles, to find D C. In the triangle, D B C, we have B C, D C, and the included angle, to find the angles, B D C and D B C. In the triangle, B C S, we have B C and the angles to find B S and C S.

The above instances are sufficient to illustrate this problem, which is extensively useful in maritime surveying to determine the positions of rocks, sands, &c., at a distance from the coast; but the operation may be very much shortened by making use of an instrument called a *station-pointer*, which can be set to the observed angles and then applied to the map or plan, so as to fix the station at once; or the observed angles may be drawn on transparent tracing-paper, and then applied to the plan; which method will be found to answer the purpose.

The following trigonometrical problem will serve to illustrate the method of carrying on a triangulation for any survey, whether the object be to find the distance between two given points, or for any other purpose whatever.

62. *Let* A B *be a base of* 2 *miles, or* 3520 *yards; and suppose poles or flag-staves are set up at the stations,* A, B, C, D, G; *and that the angles at those stations, taken with a theodolite, are the following:—*



Namely,	C A B = 64° 29′		D C G = 73° 58′
	C B A = 75 15		C D G = 51 27
	A C B = 40 18		C G D = 54 33
	Sum.. 180 2		*Sum*.. 179 58

BCD = 53° 41′	DGP = 71° 7′
CBD = 64 8	GDP = 46 51
BDC = 62 14	
Sum.. 180 3	

It is required to find the distance of the spire P *from the station* A.

The error in the sum of the three observed angles of the first triangle is 2′; in the second, 3′; and in the third, 2′. The angle at P, in the fourth triangle, is supplemental.

But no certain rule can be given for correcting the observed angles; this must be left to the judgment of the observer, who, from circumstances, will seldom be at a loss to point out where the greatest uncertainty lies. To make the calculation, however, we will suppose the corrected angles are,

CAB = 64° 28′	DCG = 73° 58′
CBA = 75 14	CDG = 51 28
ACB = 40 18	CGD = 54 34
180 0	180 0
BCD = 53 40	DGP = 71 7
CBD = 64 7	GDP = 46 51
BDC = 62 13	GPD = 62 2
180 0	180 0

Then,

ACB = 40° 18′ ..... *sin.*	9·810763
	0·189237
AB = 3520 .... log.	3·546543
CAB = 64° 28′ ...... *sin.*	9·955368
	3·691148 log. CB.

	3·691148 log. C B.
B D C = 62° 13′ *ar. co. sin.*	0·053196
B C D = 53 40...... *sin.*	9·906111
	3·650455 log. B D = 4471·5
	3·744344*
	3·744344
C B D = 64° 7′....... *sin.*	9·954090
	3·698434 log. C D.
C G D = 54° 34′ *ar. co. sin.*	0·088954
D C G = 73 58...... *sin.*	9·982769
	3·770157 log. G D.
G P D = 62° 2′ *ar. co. sin.*	0·053931
D G P = 71 7 .... *sin.*	9·975974
	3·800062 log. D P. = 6310·5

Now, from the sides, B A, B D, and the included angle, 139° 21′, we get the angle B D A = 17° 48′, and A D = 7501·1 yards.

And if B D A be taken from 160° 32′, the angle, B D P, there remains 142° 44′, the angle, A D P, which, with the including sides A D = 7504·1, and D P = 6310 5, will give the distance from P to A = 13093 yards.

When triangles are carried on from the original base in all directions, the distances towards the extremities may, in some respect, be verified by independent calculation.

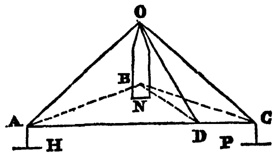
* When the two first terms of the proportion are repeated, the operation may be somewhat abridged by taking the sum of the arithmetical complement and the log. of the second term, instead of setting them down separately a second time.

Thus, 3·744344 is the sum of $\begin{cases} 3·691148 \\ 0·053196 \end{cases}$

REDUCTION OF OBLIQUE ANGLES TAKEN WITH A SEXTANT, TO THE CORRESPONDING HORIZONTAL ANGLES.

When describing the uses of the pocket-sextant, mention is made (page 102) of angles taken with that instrument not being always, like those observed with a theodolite, *horizontal ones;* but frequently in planes oblique to the horizon. Thus:—

63. *Suppose* O N *is an object standing on the horizontal plane* H N P: H A *and* C P, *two staves or rods, equal in height to that of the eye; and let the plane,* A B C, *be parallel to the horizontal plane,* H N P; *also suppose* H P *or* A C *is a base of* 250 *yards; and that the angles taken in the plane,* O C A, *are*



O A C = 56° 46′, *and* O C A = 62° 54′; *the angles of elevation* O A B, O C B, *being* 6° 40′ *and* 7° 6′ *respectively. Hence, the height and horizontal distances,* A B, C B, *are required.*

When one of the sides (A C) including an angle (O A C) oblique to the plane of the horizon, is horizontal, the angle is reduced to the corresponding horizontal angle, by the following proportion:—

As the *cosine* of the angle of elevation (O A B),
Is to the *cosine* of the given angle (O A C),
So is the *radius* or *sine* of 90°,
To the *cosine* of the reduced angle (B A C).

For let D B O be a vertical plane, and the angle A D O a right one: then the triangles A B O, D B O, being also right angled at B, we have,

Sine A B O, 90° : A O :: *sine* A O B : A B.
Sine A D O, 90° : A O :: *sine* A O D : A D.

Therefore, by equality

Sine A O B : *sine* A O D :: A B : A D :: *sine* A D B, 90° : to *sine* A B D; or, *sine* A O B : *sine* A O D :: *sine* 90° : *sine* A B D.

But A O B is the complement of the elevation; A O D the complement of the observed angle O A C; and A B D that of the reduced angle B A C; therefore,

As *cosine* 6° 40′........................	log.	9·997053
		0·002947
Is to *cosine* 56° 46′....................	log.	9·738820
So is *sine* 90°	log.	10·000000
To *cosine* 56° 31′, the reduced angle BAC..	log.	9·741767

As *cosine* 7° 6′	log.	9·996657
		0·003343
Is to *cosine* 62° 54′....................	log.	9·658531
So is *sine* 90°	log.	10·000000
To *cosine* 62° 40′, the reduced angle ACB..	log.	9·661874

Therefore, the angles of the triangle A O C, reduced to the horizontal plane, are

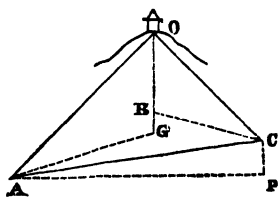
B A C = 56° 31′
A C B = 62 40
A B C = 60 49

And the side, A C, being 250 yards, we shall have A B = 254·4, and C B = 238·8 yards; whence B O = 29·7 yards: to this add N B, the height of the observer's eye above the horizontal plane, H N P, and the sum will be the whole height, N O.

But the distances, A B, C B, and height, B O, may be calculated without any reduction of angles; for A C, and all the angles of the triangle, A O C, being given, the sides, A O, C O, are found, and then the right-angled triangles, ABO, CB O, will give AB, CB, and BO, at three proportions.

And should it be necessary, the reduced angles may be found from the sides of the triangle, A B C.

64. *If* A *and* C *are two stations on sloping ground;* O *an object on the top of a hill: and the angles,* O C A, O A C *(measured with a sextant), equal* 79° 29′, *and* 63° 11′, *respectively: also suppose the angle of elevation at* A *is* 6° 36′, *at* C = 5° 22′: *what are the horizontal distances and height of the object;* A C *being* = 410 *yards.*



Let O G be perpendicular, and A G, C B, parallel to the horizon: then A G, C B, are the horizontal distances.

In the triangle, A O C, the angles are,

$$
\begin{aligned}
OCA &= 79^\circ\ 29' \\
OAC &= 63\ \ 11 \\
AOC &= 37\ \ 20 \\
\text{And } AC &= 410 \text{ yards.}
\end{aligned}
$$

Whence A O = 664·7, C O = 603·4, these hypothenuses, with the angles of elevation, O A G, O C B, in the right-angled triangles; A G O, C B O, give

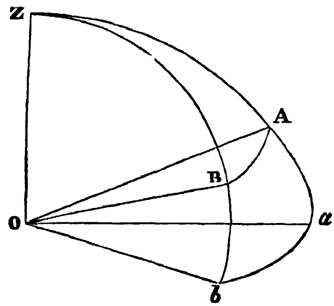
A G = 660·3, O G = 76·4, C B = 600·7, O B = 56·4 yards.

And the difference of O G and O B is 20 yards = B G = C P, the difference in the heights of the stations, A P, being supposed horizontal.

The sides, A C, C P, will give A P. And the angles of the triangle, A O C, when reduced to the horizon, may be found from the horizontal distances, A P, A G, C B, taken as the sides of a triangle.

We will add another instance:—

64. *Let* O *be the station of the observer;* A, B *the two objects between which an angle is measured; then the angle subtended by them at* O, *is* A O B, *which* A B *measures: but if* Z *a*, Z *b*, *are each* = 90°, *a b*, *and not* A B, *measures the angle a* Z *b*, *which is the angle required. We have, then, from the observed angle,* AOB, *and the observed zenith distances,* Z A, Z B, *to find the angle, a* Z *b*, *or, which is the same thing, to find the difference of the angles,* A O B, *a* Z *b*.



The last figure will be found useful, as showing the principle upon which the reductions are made; but I shall not give the calculation: niceties of this kind being unnecessary in ordinary military surveying. [See page 104.]

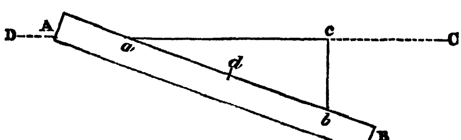
ON DRAWING INSTRUMENTS, ETC.

It may be of service for the student to know what instruments, &c., are required for making finished plans of his sketches and surveys.

A complete case of mathematical instruments is quite unnecessary. Let him be provided with a pair of pocket folding compasses of a well-known pattern, and which has been in use among military men for a long period; it contains a pencil-holder and a steel line-drawing pen. This, with the ivory rectangular protractor, mentioned in page 4, will be sufficient for all ordinary military surveying.

He will further require a pair of Marquois rulers or *scales*, with a triangular ruler, the latter of a large size; these scales used with the triangle enable us to draw parallel lines. I shall briefly describe them. The triangle is right-angled, and the hypothenuse or longest side, *a b*, is three times the length of the shortest or perpendicular, *b c*. First, for drawing parallel lines by means of one ruler and the triangle.

Let us suppose that a line, F E, is to be drawn parallel to D C; place the triangle so that one of its edges shall agree with the line, D C, and then apply



the ruler, A B, to the opposite edge; press the latter so as to keep it steady, and then slide the triangle along the scale towards A, until it arrives at the point through which the intended line is to be drawn.

But besides drawing parallel lines, we are enabled to draw them at measured distances. On each edge of the ruler are placed two *scales*, the one close to the edge, the other within this. The outer scale may be termed the artificial scale, the inner one the natural scale; the divisions on the outer are exactly three times longer than those on the inner scale, bearing the same proportion to each other that the shortest side of the right-angled triangular ruler does to the longest. The triangle has a line or mark, *d*, to serve as an index or pointer; when in use, this mark should be made to coincide with the 0 division of the scales: the numbers on the scales are reckoned both ways from this division; consequently, by confining the ruler and sliding the triangle either way, parallel lines may be drawn on either side of a given line, at any distance pointed out by the index on the triangle. Thus,—looking at the scale marked 20 (not shown in the figure), which signifies that the *inner* scale is divided to 20ths of an inch,—let us suppose that, from a given line, we want to draw a parallel line at 4-20ths of an inch distance, we have only to adjust the mark on the triangle at 0, slide it 4 divisions, and the object is effected; for the edge of the triangle only moves through one-third of the space passed over by the index.

The *scales* given are 20, 25, 30, 35, 40, 45, 50, 60; which means that the smallest divisions of the *inner* scale are in the proportion of those several numbers to one inch.

It is obvious that, by placing the rulers side by side and alternately moving them, being careful to keep one always confined, that a parallel line may be drawn at any distance.

The ruler and triangle are likewise useful when a perpendicular, or a line at right angles to another, is wanted. For instance, if a line be drawn along the edge, *c b*, it will be at right angles to D C.

It would be impossible, without giving lengthened descriptions, to show all the various uses to which the Marquois scales and triangle may be applied; but the student will find them of the greatest assistance to him, nay indispensable, in all kinds of plan-drawing; and practice will enable him to use them with facility.

ON LEVELLING.

SECTION XVII.

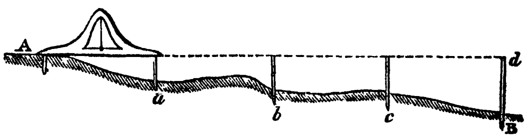
OBSERVATIONS.—LEVELLING WITH A MASON'S LEVEL.—WITH BONING STAVES.—DESCRIPTION OF A SPIRIT-LEVEL.—LEVELLING STAVES.—METHOD OF LEVELLING WITH A SPIRIT-LEVEL.—DRAWING SECTIONS.

LEVELLING may be considered as a branch of surveying; a knowledge of it, therefore, is necessary for the military surveyor. He may have to use a sloping base for a survey, which must be reduced to the true horizontal distance by levelling. Or he may have to drain a marsh; to form a road, either level, or with a certain degree of inclination; to take sections of ground for various purposes; to take profiles of fortifications and field works, &c. All such operations are performed by some kind of levelling process, as will be shown in the course of the following pages.

Writers on levelling generally commence the subject with the theoretical, and then proceed to the practical part; but I am of opinion that it would be better to set the pupil at once to work with his instruments, show him how to take levels, and thence lead him on to investigate the theoretical part. For instance, why perplex him with the spheroidal form of the globe, and its influence on levelling operations as occasioning calculations on account of curvature? Surely this, and the theory of refraction, had better be reserved until the student shall have obtained sufficient knowledge of levelling to take an interest in the art; particularly as, in practice, corrections for curvature and refraction are very rarely applied; levelling operations being usually so managed as to render such corrections unnecessary.

There are three kinds of levelling instruments in use, namely, the *ordinary Mason's level*, *Boning-staves*, and the *Spirit-level.* The two first are often employed by military men when a spirit-level cannot be obtained; or for setting off slopes, and other minor purposes.

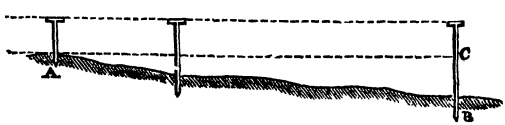
The method of using a mason's level is thus:—Suppose we want to know the difference of level between a point, A, and another at B. Drive a



picket at A down to the surface of the groun
and another, distant a few inches less than
length of the *level* at *a*, until the eye p
that the head of the latter is nearly
with A; then set the *level* to rest
pickets, and the *plumb line* wil

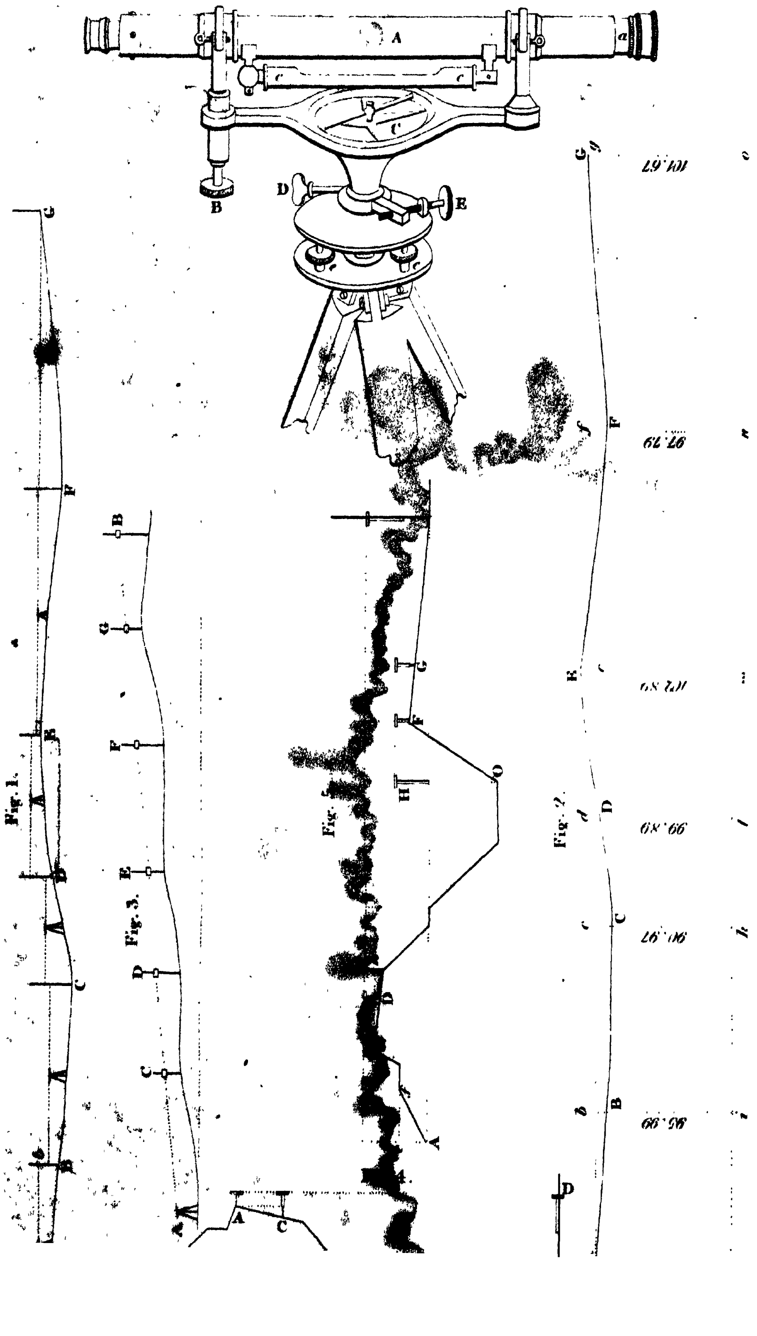
heads are truly level. A third picket is then driven in at *b*, a fourth at *c*, &c., to the heads of which the level is successively applied; and the length of the picket, B *d*, is the difference of level required: the heads of all the pickets will then be on the same level, represented by the dotted line, A *d*.

The same operation is more quickly performed by means of *boning staves*, which are simply staves of equal length (usually three feet), having a T head. To level with their assistance, a mason's level is used for the first two pickets, as before; then a third picket being driven at any convenient distance, a boning-staff is held upon each, and the third picket is driven down until the



observer at A can see that the upper surfaces of the T heads are all in an exact horizontal line: the operation may then be continued by driving in a picket beyond B, to which the boning-staff at A must be removed. Instead of driving a picket at B, a measuring-rod is often used, which being held perfectly upright a boning-staff is pressed against it, and caused to slide up or down, until its head agrees with those of the other two; when the difference of level is of course the distance between the foot, C, of the boning-staff, and B that of the

THE Y SPIRIT LEVEL.



measuring-rod. Observe that the boning-staves are to be held transversely, or at right angles to the position in which they are shown in the diagram.*

It is evident that levelling by means of a mason's level or boning-staves is only suited to very short distances; and they are but rough methods when compared to that by the spirit-level; for such is the accuracy of the process of levelling with a spirit-level, that an operation carried along a distance of several miles will not produce an amount of error equal to what will generally arise in the course of a few hundred yards, when using the former instruments.

Of spirit-levels, there are three now in use—namely, the Y level, Troughton's improved level, and Gravatt's level: these are all carefully described, and their several adjustments given, in Mr. Simms' work on instruments. I shall confine myself to the account of the Y level, as represented in plate XVI.

This instrument has an achromatic telescope, mounted in Ys, like those of the theodolite; and is furnished with a similar system of cross-wires,

* Engineers regulate slopes, such as those required in fortification, making roads, &c., by means of what is termed *Boning*. The operation is performed by driving a picket at the top, and another at the bottom of a given descent for the distance; upon these two boning-staves are held, while intermediate pickets are driven down until boning-staves, held on the heads of the latter, are seen to be in the same inclined plane with those placed at the top and bottom of the slope.

for determining the axis of the tube, or line of collimation. By turning the milled-headed screw, *A*, on the side of the telescope, the internal tube, *a*, will be thrust outwards, which carrying the object-glass, it is by this means adjusted to its focal distance, so as to show a distant object distinctly.

The tube, *c c*, carrying the spirit-bubble, is fixed to the under part of the telescope, by a joint at one end, and a capstan-headed screw at the other, which sets it parallel to the optical axis of the telescope. One of the Ys is supported in a socket, and can be raised or lowered by a screw, B, to make the telescope perpendicular to the vertical axis. Between the two supports is a compass-box, C (having a contrivance to throw the magnetic needle off its centre when not in use): it is convenient to take bearings, and is not necessarily connected with the operations of levelling, but extends the use of the instrument, making it a circumferenter. The whole is mounted on parallel plates, and three legs, the same as a theodolite.

It is evident, from the nature of this instrument, that three adjustments are necessary. First, to place the intersection of the wires in the telescope, so that it shall coincide with the axis of the cylindrical rings, on which the telescope turns; secondly, to render the level parallel to this axis; and lastly, to set the telescope perpendicular to the vertical axis, that the level may preserve its position while the instrument is turned quite round upon the staves.

TO ADJUST THE LINE OF COLLIMATION.

The eye-piece being drawn out to see the wires distinctly, direct the telescope to any distant object, and by the screw, A, adjust to distinct vision;* bring the intersection of the cross wires to coincide with some well-defined part of the object, then turn the telescope round on its axis, as it lies in the Ys, and observe whether the coincidence remains perfect during its revolution: if it does, the adjustment is correct; if not, the wires must be moved one-half the quantity of error, by turning the little screws near the eye-end of the telescope, one of which must be loosened before the opposite one is tightened, which, if correctly done, will perfect this adjustment.

TO SET THE LEVEL PARALLEL TO THE LINE OF COLLIMATION.

Move the telescope till it lies in the direction of two of the parallel plate-screws, *e e*, (the clips

* The eye-piece must first be drawn out until the cross wires are perfectly well defined; then the object-glass moved till distinct vision is obtained without parallax, which will be the case if, on looking through the telescope at some distant object, and moving the eye sideways before the eye-glass, the object and the wires remain steadily in contact; but if the wires have any parallax the object will appear flitting to and from them.

which confine the telescope in the Ys being laid open), and by giving motion to the screws, bring the air-bubble to the middle of the tube, shown by the two scratches on the glass. Now reverse the telescope carefully in its Ys, that is, turn it end for end; and should the bubble not return to the centre of the level as before, it shows that it is not parallel to the optical axis, and requires correcting. The end to which the bubble retires must be noticed, and the bubble made to return one half the distance, by the parallel plate-screws, and the other half by the capstan-headed screw at the end of the level; when, if the halves have been correctly estimated, the air-bubble will settle in the middle in both positions of the telescope. This, and the adjustment for the collimation, generally require repeated trials before they are completed, on account of the difficulty in estimating exactly half the quantity of deviation.

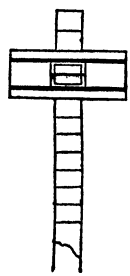
TO SET THE TELESCOPE PERPENDICULAR TO THE VERTICAL AXIS.

Place the telescope over two of the parallel plate-screws, and move them (unscrewing one while screwing up the other) until the air-bubble of the level settles in the middle of its tube; then turn the instrument half round upon the vertical axis, so that the contrary ends of the telescope may be over the same two screws, and if the bubble again settles in the middle, all is right in that position; if not, half the error must be corrected by turning the screw, B, and the other half by the two parallel plate-screws, over which the telescope is placed. Next turn the telescope a quarter round, that it may lie over the other two screws, and make it level by moving them; and the adjustment will be complete.

Before making observations with this instrument, the adjustments should be carefully examined and rectified, after which the screw, B, should never be touched; the parallel plate-screws alone must be used for setting the instrument level at each station; and this is done by placing the telescope over each pair alternately, and moving them until the air-bubble settles in the middle. This must be repeated till the telescope can be moved quite round upon the staff-head, without any material change taking place in the bubble.

OF THE LEVELLING-STAVES.

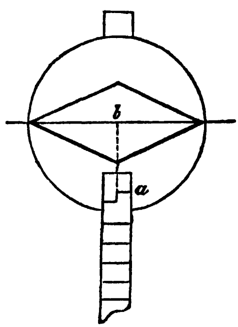
Two mahogany station-staves generally accompany the spirit-level; they consist of two parts, capable of being drawn out when considerable length is required. They are divided into feet and hundredths, or feet, inches, and tenths; and have a sliding-vane, with a wire placed across a square hole in the centre, as shown in the annexed figure;



the vane being raised or lowered by the assistant until the cross wire corresponds with the horizontal wire of the telescope, the height of the wire in the vane, noted on the staff, is the height of the apparent level above the ground at that place.

When both the staves are used they should be set up at equal distances on each side of the spirit-level; the difference of the heights of their vanes will be the absolute difference of level between the two stations. But when one staff only is employed, the difference between the height of the vane and the height of the centre of the telescope of the instrument will be the apparent difference of level; which, if the distance between the staff and instrument is great, requires to be corrected for the curvature of the earth; the method of computing which correction will be shown further on.

TROUGHTON'S LEVELLING-STAVES.



These consist of three sliding rods of mahogany, each four feet long, and they are divided into feet, &c., as those which have just been described. The sliding-vane is circular, having at the lower edge a square aperture, one side of which is bevelled; and a line on the bevelled side denotes the reading of the staff. The face of the vane is made of white holly, with an inlaid lozenge of ebony, forming at once a conspicuous object and one easy of bisection. A circular spirit-level is attached to the top of the hindermost rod, to guide the assistant in holding it perpendicular.

In levelling, the vane must be moved up or down, until the horizontal wire of the telescope bisects the acute angles of the lozenge; or, in other words, passes through its horizontal extremities, as shown in the figure.

A line on the bevelled edge at *a* (as before stated) denotes the reading of the staff; therefore a piece equal in length to the distance, *a b*, is cut off from the bottom of the staff, or rather, the divisions commence at that number of inches above 0.

When the observation requires that the vane be raised to a greater height than four feet, the object is effected by leaving it at the top of the rod in front, and then sliding this rod up upon the one which is immediately behind it; this will carry the vane up to eight feet, and from that to twelve may be obtained by similarly sliding the second upon the third rod. In the latter steps the reading is at the side of the staff, the index division remaining stationary, and at four feet from the ground; a circumstance which affords great facility in reading off.

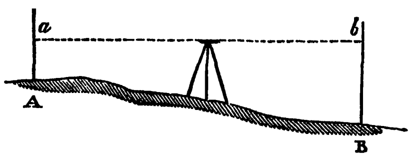
The Troughton staves, although exceedingly well-contrived and very portable, are liable to some objections, the principal of which is, that the observer must depend on his assistant to read the height observed; or, if he is not sufficiently intelligent to be entrusted with so responsible a duty, he is obliged, after the observation is made, to carry the staff to the observer, or wait for him to come and read off the height of the vane and register it in his field-book; thus occasioning great loss of time and uncertainty in the results, for the vane on the staff might possibly be shifted in the meantime. Also, when very dry, I have found the slides to slip down one or two tenths of an inch, notwithstanding every care on the part of the assistant to hold his staff steadily: a remedy has been found for these defects in

THE NEW LEVELLING-STAVES.

These have no vane to slide up and down, but the face of each staff is made broad enough to contain sufficiently large graduations and figures, for the observer to read with certainty to the one-hundredth part of a foot, at the distance of seven or eight hundred feet, which is sufficient for most practical purposes; thus securing greater certainty and expedition in the work: for it not unfrequently happened, in using the old staves, that when, by a succession of signals, the staff-holder had nearly brought the wire of the vane to coincide with that of the telescope, he would, in his attempt to perfect it, remove the vane further from coincidence than at first.

The newly-constructed staff consists of three parts, which pack together for carriage in a neat manner; and when opened out for use form a staff seventeen feet long, jointed together something after the manner of a fishing-rod: the whole length is divided into hundredths of a foot, alternately coloured black and white, and occupying half the breadth of the staff; but for distinctness the lines denoting tenths of feet are continued the whole breadth, every half foot or five tenths being distinguished by a conspicuous black dot on each side.

We shall now proceed to show how the difference of level is ascertained, between two points, A and B, a distance we will suppose of five hundred feet. Plant the spirit-level about mid-way between the two stations, taking care to press it legs firmly in the ground;



draw out the eye-piece of the telescope until the cross-wires appear perfectly well-defined; then directing the telescope to a levelling-staff, held at one of the stations, turn the milled-head, A, until the smallest graduations on the staff can be seen with clearness:* that these two adjustments be very carefully and completely performed, is of more consequence than is generally supposed, for upon them depends the existence or non-existence of instrumental parallax.

* We suppose the new levelling-staves to be used.

Having made the above adjustments perfect, bring the spirit-bubble into the centre of its glass tube, which position it must retain unmoved in every direction of the instrument; or, in other words, the bubble must indicate a true level during the time the telescope is turned completely round horizontally on its staff-head: this is accomplished by bringing the telescope successively over each pair of the parallel plate-screws and giving them motion, screwing up one while unscrewing the other to a corresponding extent, in the manner pointed for the adjustment of the theodolite, page 22.

The level being now prepared for observation, an assistant holds up the staff at A, either resting it on the ground, or what is better, upon a peg driven down to its surface: he must be careful to hold it perpendicularly. The observer now directs his telescope upon the staff, and when nearly in the right direction let him turn the clamping-screw, D, after which, by means of the slow-motion screw, E, the telescope is adjusted with greater exactness upon the staff; when the number of feet, and parts of a foot, are to be carefully noted, as cut by the horizontal wire of the telescope, and represented by *a* in the figure, the dotted line, *a b*, representing the line of sight or visual ray. The assistant then places his staff on a peg at B, and the observer (taking care to notice that the bubble of his level continues in the centre of its tube), directing his telescope, reads off as before. We will suppose that the reading with the staff at A was 3 feet and 9 hundredths of a foot, and that the reading with the staff at B was 7 feet and 11 hundredths; then the difference of level between the two stations is obtained by subtracting the less from the greater. The difference here is 4 feet and 2 hundredths.

The above is an example of simple levelling, when the stations not being more than six or seven hundred feet apart, and the inclination of the ground slight, one operation is sufficient. But when, from the distance or great steepness, several similar operations are necessary, it is called compound levelling, and a register or field-book is required to enter the observations in.

Let us now suppose a case of compound levelling, and the proceeding will be as follows—to ascertain the difference of level between two points, A and G, plate XVI., fig. 1.

Plant the spirit-level, as before, about mid-way between A and a point B, at any convenient distance, which need not be exactly in line between those points. Then the instrument being carefully adjusted, we will suppose that when directed to A, the reading on the staff *A a* is 3·07 feet, and when turned to B, that it is on the staff B *b*, 7·08 feet. The instrument being then successively placed at convenient situations between B C, C D, D E, E F, F G, let us suppose that the readings on the staves held up at A, B, C, &c., are, as entered in the field-book below:—

Back.		*Forward.*	
A	3·07	B	7·08
B	4·03	C	9·05
C	10·00	D	1·08
D	8·02	E	5·02
E	2·10	F	7·20
F	6·09	G	2·21
	33·31		31·64
	31·64		

1·67, that G is above A.

The sum of all the back readings being greater than that of the forward ones, the latter is deducted from the former, which gives 1·67 feet as the difference of level between the points A and G.

Such is the easy process, whatever the distance or nature of the ground; whether a continued descent or of an undulating character: and if a section of the ground between the points is not required, the most convenient line for the operation may be selected. But when a section is to be made, the distances between the several stations must be carefully measured, and the rises and falls of the ground reduced to the true horizontal lengths; this reduction had better be made during the operation, in order that the column of distances in the field-book may show the horizontal ones, and thus save trouble when the section is to be drawn.

The following method of obtaining the horizontal length of a slope, will be found to answer very well for short distances. Let one end of a measuring tape be held close to the ground at the upper station by an assistant; you then descend to the length of the tape, or less, if the slope be considerable, and elevate the other end, at the same time drawing tight, until the stretched tape is horizontal; when a small stone being dropped, the point where it falls will be the position from which the next measurement is to commence. But for long distances, especially when the ground rises or falls with regular slopes, it will be found better to measure the length of a slope, and afterwards reduce it to the true horizontal distance by calculation. When, however, the rise or fall is very slight, the reduction may altogether be disregarded; the difference between the hypothenusal and horizontal measurements being scarcely perceptible.

The following little table will be useful in making reductions:—

Rise in feet for one hundred.	Reduction upon one hundred feet in feet and decimals.
1	0·01
2	0·02
3	0·05
4	0·08
5	0·13
6	0·18
7	0·24
8	0·32
9	0·40
10	0·50
11	0·61
12	0·72
13	0·85
14	0·98
15	1·14
16	1·29
17	1·45
18	1·63
19	1·82
20	1·93

When an operation of levelling is performed for the purpose of obtaining a section, the form of a field-book, as follows, will be found very convenient. We shall insert the levels as in the former field-book.

LEVELLING FIELD-BOOK.

Back.	Forward.	Distance.	Difference.		Reduced Level.	
			Rise. +	Fall. —		
A 3·07	B 7·08	320	....	4·01	— 4·01	below A.
B 4·03	C 9·05	406	....	5·02	— 9·03	ditto.
C 10·00	D 1·08	240	8·92	....	— 0·11	ditto.
D 8·02	E 5·02	318	3·00	....	+ 2·89	above A.
E 2·10	F 7·20	548	....	5·10	— 2·21	below A.
F 6·09	G 2·21	625	3·88	....	+ 1·67	above A.
33·31	31·64		15·80	14·13		
31·64			14·13			
1·67			1·67			

The sign — (minus) prefixed to the 4·01 in the column of reduced levels, signifies that the point B is 4·01 feet below A: the same sign continues with the two following entries, showing that C is 9·03 feet, and D, 0·11 feet below A: but E we find to be 2·89 feet above A, and the sign + (plus) is used to denote that it is so.

The figures in the last column are obtained by addition or subtraction, as the case may require: for instance, we find that when our instrument is placed between A and B, that B reads 7·08.

$$
\begin{array}{rr}
 & 7{\cdot}08 \\
\text{and A} & 3{\cdot}07 \\
\hline
 & 4{\cdot}01 \text{ difference — fall.}
\end{array}
$$

Again, between B and C the difference of level is 5·02; the ground still falling, this must be added to the 4·01, making a total fall from A to C of 9·03 feet.

From C to D there is a rise of 8·92 feet, which quantity being deducted from 9·03, brings the levelling up to 0·11 feet of the level of A; and the rise continuing to E, which is 3 feet above D, we have (by deducting 0·11 feet that D was below the level of A) the level of E 2·89 feet above A; and so on.

It is a proof that the field-book has been correctly kept, when the difference between the totals of the back and forward stations, and that between the totals of the rises and falls, agree with the last reduced level: thus, by reference to the above example of a field-book, it will be seen that this condition is fulfilled; 1·67 feet appearing in the proper columns as the height of G above A.

TO DRAW THE SECTION.

Rule a straight line, A *g* (plate XVI., fig. 2), to represent an horizontal line at the level of A; this is termed a *datum line:* along it, set off A *b* equal to 320 feet, namely, the *horizontal* distance from A to B, as entered in the field-book: from the point *b*, let fall a perpendicular, and make $b\,B = 4{\cdot}01$. Join A B. The $b\,c = 406$ feet, and make the perpendicular, $c\,C = 9{\cdot}03$ feet. Join B C. In the same manner proceed with the *section*, letting fall or raising perpendiculars, *d* D, *e* E, &c., according as the field-book entries carry the section below or above the datum line, A *g*.

In setting off on the datum line, each distance separately (as above described), you carry forward whatever error may have been made in taking any of them from the scale. To do away with this source of error, it is better to add the measured lengths together, each to the sum of those preceding it; thus obtaining the absolute length of every station from the starting point; and by setting them off in this way, the height of each will be placed on the section in its correct relative situation; and should an error be committed in marking off any point, it does not affect the rest.

If the foregoing method of reducing levels be found difficult or troublesome, on account of the introduction of plus and minus signs, they can be dispensed with, as well as the columns of "Rise" and "Fall," by proceeding in the following manner:—Assuming the starting point to be any even number of feet high; or, what is the same thing, assume a datum line any even number of feet below the starting-point, as 100; taking care that your choice falls upon a number greater than the number of the whole fall you are likely to experience in the operation; then from this assumed height *subtract* the reading of the forward, and to the remainder *add* the reading of the back-staff, the result will be the height of the first forward station above the assumed datum line; then from this height subtract the next forward reading, and to the remainder add the reading of the back-staff, the result will be the height of the second forward station above the assumed datum; and so on throughout the whole levelling operation. The difference between any two of the readings will be the difference of level between the corresponding points on the ground.

By way of illustration, we will reduce part of the foregoing example after this manner, and the student can then adopt whichever method he may consider the best.

Back Sight.	Forward Sight.	Reduced Levels.	REMARKS.
		100·00	Assumed datum.
3·07	7·08	7·08	
		92·92	
		3·07	
		95·99	Height of 1st former station [above assumed datum.
4·03	9·05	9·05	
		86·94	
		4·03	
		90·97	Ditto 2nd ditto ditto.
10·00	1·08	1·08	
		89·89	
		10·00	
		99·89	Ditto 3rd ditto ditto.
8·02	5·02	5·02	
		94·87	
		8·02	
		102·89	Ditto 4th ditto ditto.
2·10	7·20	7·20	
		95·69	
		2·10	
		97·79	Ditto 5th ditto ditto.
6·09	2·21	2·21	
		95·58	
		6·09	
		101·67	Ditto 6th ditto ditto.

If, after adopting the latter mode, it should be required to reduce the levels to that of the starting point as a datum, nothing more is required than to take the difference between the height thus found, and that of the assumed datum: thus, in the above example, subtracting 95·99, the height of the first forward station, from 100 (the assumed datum) we have 4·01 for its height below the starting point: next, taking 90·97 from 100, leaves 9·03 for the quantity that the second forward station is below the level of the starting-point; and so of the rest. Or it may be done much easier after the section is made to the assumed datum, by drawing a line parallel thereto through the point, A, or any other that may be determined on: thus, the section may be at once adapted to any required datum line.

Fig. 2, plate XVI., also shows the mode of drawing a section, according to the latter way of keeping the register. *h o* represents the datum line; *h i*, *i k*, *k l*, &c., the distances from station to station; perpendicular lines, *h* A, *i* B, *k* C, &c., being drawn to *h o*; *h* A is made 100 feet (the assumed datum), *i* B 95·99, the height of the first forward station above the assumed datum; *k* C 90·97, the height of the second forward station above datum; and so on.

It may here be observed, that when a section is made of a considerable length of ground for railway, canal, or other purposes, two scales are used, one for the horizontal distances, the other for the vertical heights and depths, which produce a caricatured representation of the country; but by making the vertical scale much larger than the horizontal one, the depths of cutting and embankment required in the execution of road, railway, or canal works, is shown with greater clearness than if both scales were equal. Civil engineers usually take 4 inches to a mile for the horizontal scale, and 100 feet to one inch for the vertical one.

When a section of a line of country has been completed (for any purpose whatever), it is in most cases necessary to check its accuracy by repetition; but in doing this it is seldom requisite to level over precisely the same line of ground, unless there is cause to suspect its general correctness, but to follow the most convenient and nearest route, and at intervals to level to some known points on the exact line of section, which will give *their* difference of level: the points thus selected are generally what are called *bench* marks, and are nothing more than marks or notches cut upon gate-posts, stumps of trees, mile or boundary stones, or any similar immoveable objects, contiguous to the line of section, and at frequent intervals. These bench marks are made by the person who takes the section in the first instance, and are sometimes previously determined upon. When the section is complete, their relative heights with regard to the base line, or datum of the section, become known; consequently, they may be considered as so many zero or fixed points on the line, easily recognisable, from whence any portion of the work may be levelled over again; or branch lines of level may be conducted in any direction, and the levels of such branches be comparable with those of the main line.

LEVELLING WITH A THEODOLITE.

The use of the theodolite, as a levelling instrument, consists in taking a series of angles of elevation and depression along the line, the section of which is required. To do this, it is only necessary to set the instrument up at every spot on the line of country to be levelled, where the inclination changes, without regard to the minor inequalities of the surface, taking care that the adjustments have been carefully examined and rectified, as explained in Section XIV.; especially those which set the line of collimation and the spirit-level attached to the telescope parallel to each other. Then set the instrument level, by means of the parallel plate-screws, as directed at page 22; and direct an assistant to go forward with a staff, having a vane or cross piece fixed to it, exactly at the same height from the ground as the centre of the axis of the telescope. Having gone to the forward station, the assistant must hold the staff upright whilst the observer measures the vertical angle, which an imaginary line, connecting the instrument and staff, makes with the horizon; the instrument and staff should then change places, the same angle should be taken back again, and the mean taken as the correct result.

The distance must then be measured, which it will be evident is the hypothenuse of a right-angled triangle; the perpendicular of which is the difference of level to be obtained by calculation from the following

RULE. *Add together the logarithm of the measured distance and the log-tangent of the observed angle; the sum, rejecting ten from the index, will be the log. of the difference of level in feet, or as the distance was measured in.*

In this manner, by considering the surface of every principal undulation as the hypothenuse of a right-angled triangle, the operation of levelling may be carried on with great rapidity; but with less accuracy than by the spirit-level. An example of this kind of levelling has been given.

Another method of applying a theodolite to the purposes of levelling, is to set up the instrument at the foot of an inclination; thus, suppose the theodolite placed at A, fig. 3, plate XVI, and the telescope elevated so that the line of sight, A B, may coincide with the vane on a staff, exactly at the same height from the ground as the instrument; suppose the staff held at B, the angle of elevation being carefully noted, the instrument must remain perfectly steady, whilst the observer is watching an assistant passing along the line with a staff, which he successively holds up at every change of inclination, as C, D, E, &c., the staff-holder raising or lowering the vane until the observer perceives the cross wires of the telescope (or line of sight, A B) to coincide with that on the vane; the height of the staff is then read off and noted, which gives the depression of that spot of ground below the line, A B; which being done along the whole distance, and a mark made on the ground at each spot, that the distances may likewise be measured, the undulations of the surface below the line, A B, is determined, and the inclination of the line of sight being likewise obtained with the theodolite, the requisite data for drawing the section are obtained: and it will easily be seen that, when the ground is irregular, the section will be obtained with greater exactness when the stations, or points where the staff is held up, are very numerous.

After having obtained the difference of level from station to station, either with a spirit-level or theodolite, the rate of inclination of the surface may be found by dividing the distance by the difference of height; thus, if the distance be 760 feet, and the height 38 feet, 760 divided by 38 gives 20; showing the rate of inclination to be 1 in 20.

Probably sufficient has now been said, as regards the practical part of the subject, to enable a student to understand and practice all ordinary levelling operations; but one or two examples of the methods pursued by military men, when taking sections for the purpose of profiling and defilading field-works, &c., &c., may be useful.

1. We will suppose that, for some military object, it is necessary to ascertain the difference of level between the crest of the parapet, A, and the foot of the glacis, B, fig. 4, plate XVI.; and that the following implements only are at hand, namely, a 10-feet rod, two boning-staves of 3 feet, a staff of similar form, that is, with a T head of 6 feet, and a mason's level.

Drive a picket at C, and level the top of it with the point, A, by the mason's level. Next send a man to the foot of the glacis at B, and let him hold up the 10-feet rod, against which he must slide the 6-feet staff, until the top of it, D, is found to be on a level with the boning-staves held at A and C; when it is evident that the point to which the head of the staff at D reaches along the 10-feet staff, deducting 3 feet (length of the staff at A), will be the difference of level required.

2. We will suppose that a section of a field-work is to be made by means of the same implements. Fig. 5, plate XVI.

Here it is only necessary, after the head of a picket driven at D is made level with the point, C, to cause an assistant to hold up the 10-feet rod at the foot of every slope, along which he is to slide the 6-feet boning-staff, until it appears on a level with the staves held up at C and D. The horizontal length of each slope is easily determined by resting the 6-feet staff on the level part at the bottom, taking care to hold it perpendicularly, while the 10-feet rod is applied in an horizontal position, as from *e* to *f*, *c* to *h*, &c.

Should the bottom of the ditch be too low for the long rods to reach up to the level of the staves at C and D, the level of the crest of the glacis at F may be taken, and a picket driven at G to the level of F, when the length, H O, may be observed.

With a spirit-level it would only be necessary to plant the instrument on the banquette at *f*, and hold up the regular levelling-staff at the foot of each slope, as described above.

To draw the section it will merely be requisite to rule a line, and having set off upon it the horizontal lengths of the several slopes, let fall perpendiculars from the points obtained, along which distances are to be taken corresponding with the levelling.

TABLE*

Showing the reduction in feet and decimals upon 100 feet, for the following angles of elevation and depression.

Angle.	Reduction.	Angle.	Reduction.	Angle.	Reduction.
3° 0′	0·14	9° 0′	1·24	15° 0′	3·40
		30	1·38	30	3·64
4 0	0·25	10 0	1·52	16 0	3·88
		30	1·68	30	4·12
5 0	0·38	11 0	1·84	17 0	4·37
		30	2·01	30	4·63
6 0	0·55	12 0	2·19	18 0	4·90
30	0·65	30	2·37	30	5·17
7 0	0·75	13 0	2·56	19 0	5·44
30	0·86	30	2·77	30	5·74
8 0	0·98	14 0	2·97	20 0	6·03
30	1·10	30	3·18	30	6·33

The reduction for 100 feet (from the above table) multipled by the number of times 100 feet measured, will give the quantity to be subtracted from the measured length of an inclination to reduce it to the horizontal distance.

TABLE

Showing the rate of inclination of inclined planes for the following angles of elevation.

Angle.	One in	Angle.	One in	Angle.	One in
0° 15′	228	3° 30′	17	7° 0′	8
0 30	114	3 45	16	7 30	7¼
0 45	76	4 0	15	8 0	7
1 0	56	4 15	14	9 0	6½
1 15	46	4 30	13	10 0	6
1 30	38	4 45	12	11 0	5¾
1 45	32	5 0	11½	12 0	5½
2 0	28	5 15	11	13 0	5
2 15	26	5 30	10½	14 0	4½
2 30	23	5 45	10	15 0	4
2 45	21	6 0	9½	16 0	3¾
3 0	19	6 30	9	17 0	3½
3 15	18	6 45	8½	18 0	3¼

* This table is formed by simply subtracting the natural cosines of the angles from the radius 100.

TRACING CONTOUR LINES.

At page 89, mention is made of the contour method of delineating the features of ground, but an explanation of the way in which the contours are to be traced was necessarily deferred until I came to treat of levelling. I shall now give the process, as described by Captain Frome, R. E.

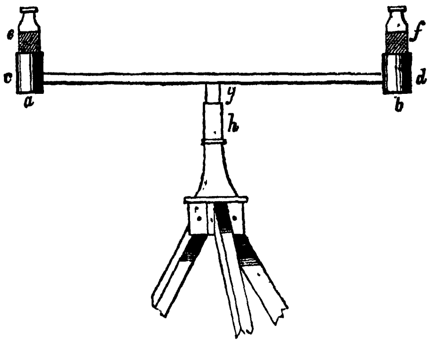
"The method of tracing these contours on the field is simply thus:—Bandrols or long pickets are first driven, one at the top and another at the bottom of such slopes as best define the ground, particularly the *ridge-lines* and *water-courses.* Should no such *sensible lines* exist, they must be placed at about equal intervals apart, regulated by the degree of minutiæ required, and the variety in the undulations of the surface of the ground. A short picket being driven on the level of the intended upper (or lower) line of contours, and in line between two of the bandrols, the level is placed so as to command the best general view of this first line, and adjusted; care being taken that its axis is not so low as to cut the ground below the picket (or so high as to be above the top of the levelling-staff, if the lower contour is the first traced); the staff is then placed at this picket, and the vane raised or lowered till it is intersected by the cross-wires of the telescope; the staff, with the *vane kept to this height*, is then shifted to another point on about the same level, and in the line between the next two pickets, and *the staff itself* moved up or down the slope till the vane again coincides with the cross-wires, at which spot another picket is driven. This operation is continued till it is necessary to move the level to continue the same upper contour-line, when (the staff being placed at one of the pickets just driven) the vane is again raised or lowered to suit the new position of the axis of the instrument, and then kept at this height as before for the continuation of the line. To trace the next contour-line, it is merely necessary to raise the *vane* on the staff, five or whatever number of feet may be the vertical distance determined upon, and proceed as before. When the level itself has to be moved to lower ground, it must be so placed that its axis will cut the ground above one of the pickets of the line just marked out, and the same quantity of five feet, added to the reading of the staff at this picket, will give the height of the vane for the next lower horizontal line.

"The use of driving all these pickets, marking out the contours nearly in the same line down the slopes, becomes evident when they are to be laid down on the plan; the places of the original bandrols or long pickets being fixed, with reference to each other, it is only necessary to measure between them, entering the distances on these lines, with the offsets to the right or left, to the different short pickets marking the horizontal lines."

This process of tracing contour lines, by means of the *spirit-level,* occupies necessarily much time, and is only suited to the object of obtaining an exact delineation of ground, to a limited extent, for engineering purposes; and a moment's consideration will convince any one that it is unsuited to the business of the *military surveyor;* whose object in general is to give a rapid delineation of portions of country, more or less extensive, with sufficient accuracy for ordinary military objects instead of working in the slow and methodical manner of an engineer, when making a plan of ground with a view to constructing upon it a fort or a fortress.

French engineers, as I am informed, make little use of the spirit-level in tracing contours, for the distances being short, a less accurate instrument answers the purpose sufficiently well. The *water-level,* which is a very simple one of their invention, is suitable for tracing contours, as well as performing other ordinary levelling. It requires no adjustments, may be made for a few shillings, and in short distances no great error can be made when using it, as may happen with a badly-adjusted spirit-level, the horizontal line being adjusted by the law of fluids; it has, moreover, this great advantage in the eyes of military men that any common workman may construct it. Captain Frome mentions that he had one made by an ironmonger in Chatham, which, being tried against a very good spirit-level, was found to give a perfectly satisfactory result.

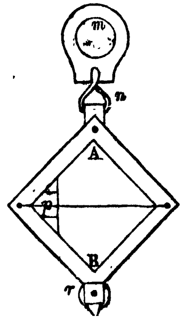
"*a b* is a hollow tube of brass, about half an inch in diameter, and about three feet long; *c* and *d* are



short pieces of brass tube of larger diameter, into which the long tube is soldered, and are for the purpose of receiving the two small bottles, *e* and *f*; the ends of which, after the bottoms have been cut off by tying a piece of string round them when heated, are fixed in their positions with putty or white lead; the projecting short axis, *g*, works (in the instrument from which the sketch was taken) in a hollow brass cylinder, *h*, which forms the top of a stand used for observing with a repeating-circle; but it may be made in a variety of ways, so as to revolve on any light portable stand. The tube, when required for use, is filled with water (coloured with lake or indigo), till it nearly reaches to the necks of the bottles, which are then corked for the convenience of carriage. On setting the stand tolerably level by the eye, these corks are both withdrawn, which must be done carefully and when the tube is nearly level, or the water will be ejected with violence; and the surface of the water in the bottles being necessarily on the same level, gives a horizontal line in whatever direction the tube is turned, by which the vane of the levelling-staff is adjusted."

A more recent invention of our clever neighbours, the French, is the "Reflecting-level," by Col. Burel of the Corps du Génie.

"The principle upon which this instrument acts is implied by its name. In a plane mirror the rays are reflected as though they diverged from a point *behind* the mirror, situated at precisely the *same distance in rear of its surface, as the object itself is in front.* If the mirror be vertical *the eye and its image are on the same horizontal line;* and any object coinciding with these is necessarily on the *same level.* It appears then only requisite to ensure the verticality of a small piece of common looking-glass, set in a frame of wood or metal, to be able, without further assistance, to trace contour-lines in every direction, or to take a section on any given line. The mirror, A B, is only one inch square, fixed against a vertical plate of metal, weighing about one pound, and suspended from a ring, *m*, by a twisted wire, *n*; so that it may hang freely, but not turn round on its axis of suspension. It can



either be used for sketching in the field, being held by this ring at arm's length; or fixed for greater accuracy in a frame which fits upon the top of the legs of a theodolite, with a bar of metal like a bent lever, pressing so slightly against it from below that it may check any tendency to oscillation, and at the same time not prevent the mirror from adjusting itself by its own weight.

"The required verticality of the plane of the mirror is thus ascertained:—a level spot of ground is chosen, where it is suspended in its frame (the simple level, without the frame, only appears in the figure given above), on any temporary stand, placed forty or fifty yards from a wall; and the prolongation of the line of sight, *from the eye to its image,* coinciding with a fine silk thread across the centre of the mirror, is marked on the wall, which is visible through a small opening, *p*, in the metal frame. The mirror is then turned round, and the observer, placed between it and the wall, with his back to the latter, notes the spot when the *image of his eye* coincides with the reflected wall *above or below the former mark.* The mean distance between these two points is assumed and marked; and by turning a screw at *r*, the centre of gravity of the mirror is altered until the image of the eye, coinciding as before with the silk thread, agrees also with this central mark on the wall. It would, perhaps, be a better plan to send an assistant some distance behind the mirror, with a levelling staff, the vane of which could be raised or lowered to coincide with the line of sight; on reversing the mirror (the staff remaining stationary) the vane would be again moved, until its reflected zero mark is cut by the thread, on a level with the image of the eye; and, finally, the mirror adjusted to the screw, to the mean between these two heights: this method admits, apparently, of greater nicety than a chalk-mark on a rough wall.

"The reflecting-level is not generally known in this country; but for many purposes it is superior to any other description of instrument, particularly for tracing contour lines on the ground in a military sketch. It is peculiarly simple in its construction; is easily managed; easily adjusted; is not liable to have this adjustment deranged, or to be injured by a fall; is, from its size, more portable than any other instrument, and can be used either held at arm's length, or *at a distance of several feet;* in which position, the length of the line of sight ensures the greatest accuracy."

Such is the opinion of Captain Frome. But I shall extract from the second volume of professional papers of the Royal Engineers, a portion of the Report of a Committee of French Engineers upon this instrument:—

Water-Level compared with the Reflecting-Level.

"The water-level is uncertain, troublesome in confined places and rugged ground. Its form renders it sensible to the least wind or sudden jerk; its fall may even destroy it, and render null many of the preceding observations. One person is always required to carry it; and continual attention must be directed to preserve the level; and the line of sight seldom or never exceeds three feet.

"The reflecting-level, on the contrary, from its size, is not affected by the wind, or being accidentally touched. Its fall does it no injury: it is easily carried, and may be used without a stand, by hanging it from a tree, at a window, or, in a word, without any trouble whatever. Little space is required for using it, as the length of the line of sight is optional, and may be as much as twenty-six feet. Again, it may be made of the commonest materials, such as hard wood, if brass, silver, or platinum cannot be obtained.

"If it be true, that the reflecting-level has so many advantages over the water-level, when they are both placed on the ordinary tripod or stand, its superiority will be still more displayed in such hasty observation as may be necessary to an army in the field, where it will be sufficient to hold it at arm's length, and equal correctness will be obtained as with the water-level, which requires more time and greater care. Why is this? We know that a pendulum will oscillate a long time when suspended from a fixed point; but if it be attached to another which also oscillates in proportion to its length, the oscillations of the pendulum, checked by those of the support, are soon shortened and annihilated: any one may verify this fact, by suspending a weight from the finger, and swaying it gently as it oscillates.

"To level in this manner, the instrument must be held at arm's length, and at the same height as the eye. Take advantage of one of its short moments of repose, which are nearly periodical, and make the observation which, though furtive, will be more correct than might be expected, since in repeating it immediately afterwards, by a second and third *coup-d'œil,* it will be seen that these last results differ very slightly from the first.

"This precision may be augmented by suspending the instrument from an arm, at the end of a short staff, set up to the requisite height.

"In this manner, observations may be taken in every direction without a stand or choice of station, only stopping to make the necessary note; and it is most convenient in levelling gently undulating ground, or in filling up the details between two horizontal contours.

"Thus, in taking the height of several hills, varying from 190 to 260 feet of elevation, which had been previously levelled, it was found that the greatest errors did not exceed six inches; so much for its correctness: and for celerity, upwards of sixty acres have been levelled in a single day by horizontal contours, distant only one yard from each other, and with the assistance of a single aid to carry the staff."

Another little instrument which, from its portability, simplicity, and the ease with which it is made, viz., the "Clinometer" (noticed at p. 94), must not be forgotten as an aid in tracing contour lines.

I have been careful to draw attention to the more simple levelling instruments, as a spirit-level is both too heavy and costly, to form part of a staff or engineer-officer's field equipment.

I understand that Colonel Colby, R.E., who now so ably directs the Trigonometrical Survey of the British Islands, has caused the contour system to be practised in delineating the ground, and I make no doubt of this method becoming general whenever a very exact representation of ground is required; but for the ordinary sketches and plans of the military surveyor, the system can neither be exercised with sufficient rapidity, nor, so far at least as I may pretend to offer an opinion on the matter, is such great precision necessary.

SECTION XVIII.

THEORY OF LEVELLING.—TERRESTRIAL REFRACTION AND CURVATURE.—LEVELLING BY THE MOUNTAIN BAROMETER.

LEVELLING is the art of finding how much higher or lower any given point on the surface of the earth is, than another given point on the same surface; or, in other words, the difference of their distances from the centre of the earth.

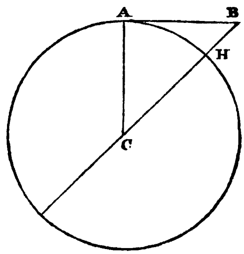
Those points are said to be *level* which are equidistant from the centre of the earth; the art of levelling therefore consists,

1st. In finding two or more points that shall be in the circumference of a circle, whose centre is that of the earth.

2nd. In comparing the points thus found with other points, in order to ascertain the difference in their distances from the centre of the globe.*

Let the circle in the annexed figure represent the earth, C its centre, and A B a tangent. Then

* The figure of the earth is not that of a perfect sphere; being somewhat flattened at the poles. The length of the *equatorial* diameter being 7924 miles, and that of the *polar* diameter 7898 miles. For our present purpose, it is sufficiently correct to consider it as a sphere.



A B represents the apparent, and A H the true level; the points, A and H, being equi-distant from the centre, C. When we say that A B represents the apparent level, we mean that it is the line which a spirit-level, or any other mode of levelling, would trace, forming a tangent to the earth's surface. Hence the difference between the true and apparent level is expressed by H B. Now, the circumference of the globe being nearly, in round numbers, 24,000 miles, the difference between the true and apparent level of any two points, as A and H, in that circumference, is scarcely perceptible when their distance from each other is less than 1000 feet. For instance, the difference in a distance of one chain, or 66 feet, is ·000104. In practice, therefore, no correction is applied during ordinary levelling operations for less distances than 1000 feet.

The rule for finding H B, whatever the distance of A H, is deduced from the geometrical theorem, that the rectangle, $2\,CH + HB \times HB$, is equal to the square of the tangent A B; hence, $2\,CH + HB : AB :: AB : HB$. But, at ordinary levelling distances, H B may be considered as nothing when compared with the diameter of the earth. Also A H may be taken as equal to A B. Then,

$2\,CH : AB :: AB : HB$; or AB^2 AH^2

very nearly. By which it appears, that the difference between the true and apparent level is equal to the square of the distance between the stations, divided by the diameter of the globe. It is, therefore, always proportional to the square of the distance.

The mean diameter of the earth being nearly 7916 miles, if AH be considered as one mile, then $\frac{AB^2}{2\,CH} = \frac{1}{7916}$ of a mile, or 8·004 inches. At two miles, it is four times that quantity, or 32·016 inches; at three miles, it is nine times that quantity, or 72·036; and so on, increasing in proportion to the square of the distance. It is convenient to reject the decimal ·004, and assume the difference between the true and apparent level for one mile to be exactly eight inches, or two-thirds of a foot. We then obtain the following form for computing the correction of level in feet due to the curvature of the earth, for distances given in miles, which may easily be remembered:—

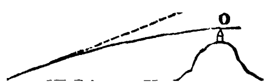
$$\text{Correction} = \frac{2\,D^2}{3}$$

D being the distance in miles. Or, in other words—*Two-thirds of the square of the distance in miles will be the amount of the correction in feet.*

TERRESTRIAL REFRACTION AND CURVATURE.

On all occasions, when from the distance between two stations, in levelling, a correction becomes necessary on account of *curvature*, a second correction is essential for *refraction*. The effect of refraction is to cause all objects, when viewed from a distance, to appear higher than they really are.

Let E be the place of an observer's eye, E H an horizontal line, and O an object on the summit of a distant hill, O, E, and H being in a vertical plane.



Then, if the rays of light proceeded from the object, O, to the eye at E in a straight line, the object would appear in its true place at O, and O E H would be the angle of elevation (considering E O as a right line); but the rays in passing through the atmosphere are continually attracted downwards from a rectilinear direction, by which means the object is seen in the direction, E T, which is supposed to be a tangent to the curve at E, and therefore the apparent or observed elevation is the angle, T E H; and the angle, T E O, or rather the angle comprehended by T E, and a right line from O to E, will be the refraction.

This refraction, which is called the *terrestrial*, to distinguish it from that which affects the altitudes of heavenly bodies, is not constant at the same elevation and distance, but is found to vary with the changes in the atmosphere, as heat, a different density, moist vapours, &c., &c. At the distance of eight or ten miles it is sometimes no more than about thirty seconds, but in particular states of the air we find it amount to upwards of two minutes.

In all surveys where great accuracy is required, corrections for curvature and refraction should be made whenever the distances of observed objects exceed 1000 feet.

The amount of refraction is estimated in various ways; some writers allow 1-10th of the distance observed, expressed in degrees of a great circle; others 1-11th, 1-12th, and 1-14th; but the mean, or 1-12th, has been most generally used.

The following mode will be found sufficiently accurate for reducing the observed angle:—

Divide 1-12th of the distance between the objects by 101·42 (the number of feet answering to one second of a degree), the quotient will give the number of seconds contained in that distance, which must be taken from the observed angle.

EXAMPLE.

The distance being 47,520 feet (9 miles), and the angle of altitude 1° 40′ 20″, the correction will be as follows:—

$$47520 \div 12 = 3960 \div 101{\cdot}42 = 39''.$$

Observed angle..........	1° 40′ 20″
Correction for refraction ..	0 0 39
Corrected angle	1 39 41

Or the correction for refraction may be obtained thus:—take 1-9th of the square of the distance in miles for the number of feet. Suppose the distance 9 miles, as above, then 9 feet is the allowance for refraction; for $9 \times 9 = 81 \div 9 = 9$. Which will be found to correspond with 39″, deducted from the observed angle.

When 2-3rds of the square of the distance in miles are taken for the number of feet on account of curvature, 1-6th of such number of feet will give the allowance for refraction. Refraction is always a *minus* quantity: curvature may be either plus or minus, according as the observed object is elevated or depressed.

Let A and B represent two stations, distant from each other 9 miles, with observed and corrected angle, as above.

Calculation with corrected angle,

Log. of distance A B 47520 feet	4·6768764
Log. tangent of corrected angle....	8.4624704
	3·1393468

3·1393468 =	1378·3
Add curvature	54
Total height..	1432·3

Calculation with angle as observed = 1° 40′ 20″

Log. A B	4·6768764
Log. tangent of observed angle...	8·4652947
	3·1421711
3·1421711 =	1387·3
Correction of curvature and refraction for 9 miles, viz., $9 \times 9 = 81 \times \frac{2}{3} =$ 54, or curvature, from which $\frac{1}{6}$, or 9, is deducted for refraction, leaving 45 (see table).....................	45
Total height....	1432·3

TABLE

For curvature and refraction from 1000 *to* 63360 *feet, or* 12 *miles.*

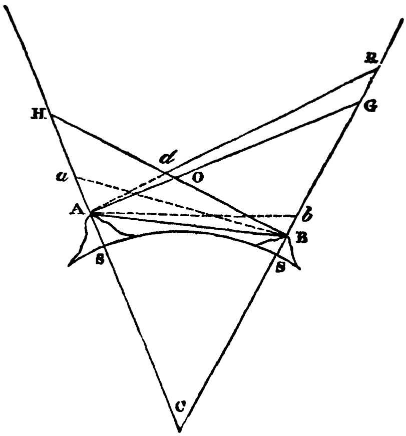
Miles reduced to feet.		Correction in feet and decimals for curvature and refraction.	Miles reduced to feet.		Correction in feet and decimals for curvature and refraction.
Miles.	Feet.		Miles.	Feet.	
	1000	·02		4500	·40
$\frac{1}{4}$	1320	·03	1	5280	·55
	1600	·05		6000	·71
	2000	·07	$1\frac{1}{4}$	6600	·86
$\frac{1}{2}$	2640	·14		7000	·96
	3000	·18	$1\frac{1}{2}$	7920	1·25
$\frac{3}{4}$	3960	·31		8500	1·42

TABLE *continued.*

Miles reduced to feet.		Correction in feet and decimals for curvature and refraction.	Miles reduced to feet.		Correction in feet and decimals for curvature and refraction.
Miles.	Feet.		Miles.	Feet.	
1¾	9240	1·70	5¾	30360	18·36
2	10560	2·22	6	31680	20·0
	11000	2·40	6¼	33100	21·70
2¼	11880	2·81	6½	34320	23·47
2½	13200	3·47	6¾	35640	25·31
2¾	14520	4·20	7	36960	27·22
3	15840	5·0	7¼	38280	29·20
	16000	5·1	7½	39600	31·25
	16500	5·26	7¾	40920	33·36
3¼	17160	5·40	8	42240	35·55
3½	18480	6·8	8¼	43560	37·81
	19000	7·16	8½	44880	40·14
3¾	19800	7·81	8¾	46200	42·53
4	21120	8·89	9	47520	45·0
4¼	22440	10·03	9¼	48840	47·53
4½	23760	11·25	9½	50160	50·14
4¾	25080	12·53	9¾	51480	52·81
5	26400	13·89	10	52800	55·55
5¼	27720	15·31	11	58080	67·22
5½	29040	16·80	12	63360	80·0

The allowance made here for refraction of 1-12th may be considered as sufficiently exact for ordinary occasions: when extreme accuracy is required, the precise amount of refraction must be ascertained at the time of observation, in the manner practised during the great trigonometrical survey by Mr. Dalby and others, which was thus:—

Let A and B be two stations, S S the intercepted or corresponding arc of the earth's circumference, C the centre of the earth; A G, B H, the horizontal lines at A and B, drawn to meet C G, C H.



An instrument being at each of the stations, A and B, the reciprocal observations are made *at the same instant of time*, which is determined by means of signals or watches, previously regulated for that purpose; that is the observer at A takes the depression (for example) of B, while the other person at B observes the depression of A.

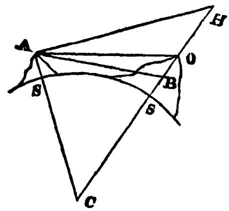
If *a* and *b* represent the apparent places of the objects, A and B the angle, *b* A B is the refraction at A, and *a* B A that at B; therefore, half the sum of the angles will be the refraction, if we suppose it equal at each station.

In the quadilateral, A O B C, the angles at A and B are right ones, therefore the sum of the other two angles at O and C, are equal to two right angles, and consequently the angles, O A B, O B A, are together equal to the angle, C, or arc, S S; therefore if the sum of the two depressions or angles, H B a + G A b, be taken from the sum of the angles, H B A + G A B, or the angle, C, the remainder is the sum of both refractions or angles, a B A + b A B; therefore *half the difference between the sum of the two depressions and the contained arc*, S S, *(or angle*, C*), is the refraction.*

If one of the objects (B), instead of being depressed is elevated, suppose to the point, R, then the sum of the angles, d A B + a B A, will be greater than the sum, O A B + O B A (or angle, C), by the angle of elevation, R A G; but if from the sum, d A B + d B A, we take the depression, H B a, there will remain d A B + a B A, the sum of the two refractions: therefore, *if the depression be subtracted from the sum of the contained arc and elevation, half the remainder is the refraction in the case.*

It is almost unnecessary to remark that the distance between the places of observation, A and B, should be known sufficiently near to give the contained arc, S S, true to a very few seconds of a degree; the refraction, however, is generally too minute to be of consequence in the operations with a common theodolite, which are usually confined to moderate distances.

Mr. Dalby's illustration of the method of ascertaining the allowance to be made for curvature may be useful to the student; I shall therefore transcribe it:



Let A be the place of the instrument, O an object on a distant hill, C the centre of the earth, C S = C S, the earth's radius, S S, the contained arc of the earth's circumference, and A H the horizontal line meeting, C S produced; the angle, C A H, being a right one. Make C B = C A, then the points A and B are the same height above the earth's surface, and B O will be what the object, O, is higher than the station, A.

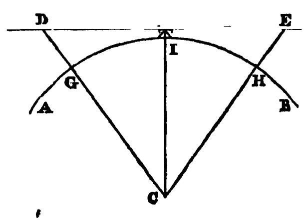
Now suppose the observed depression of the object, O, to be 2′ = the angle, H A O, and its distance 17230 yards = A B, or the arc, S S; then taking 69 1-6th miles = 1 degree, we have 69 1-6th × 1760 : 60′ : : 17230 : 8′·5 nearly the arc, S S, or angle, C. And because the triangle, A B C, is isoceles, the angle, B A C + ½ angle, C, is equal to a right one, but the angle, B A C + B A H, is also a right one, therefore B A H = ½ angle C = 4′·25; and allowing ·75 of a minute for the effect of refraction, we have 2′+·75 = 2′·75 the depression, H A O, corrected for refraction: therefore B A H — H A O = B A O, or 4′·25 — 2′·75 = 1′·5 angle, B A O; whence (supposing A B O to be a right angle), it will be radius : tangent 1′·5 : : 17230 (A B) : 7·52 yards = B O, or what the object, O, is higher than the station, A.

Hence it appears that, when two objects (A and B) are on the same level, or at equal distances from the centre of the earth, the true angular depression of one below the horizon of the other, will always be equal to half the number of degrees in the arc contained between them, supposing the earth to be a sphere.

The correction, ·75 of a minute, is between 1-11th and 1-12th of the contained arc; in some publications, however, we find 1-10th has been adopted, and others 1-14th; but neither can be depended upon as very correct.

This example is sufficient to point out the method of computation when the object (O) is below the point, B, or above the horizontal line, A H.

I shall terminate the subject of levelling with an explanation of the principle upon which we proceed when we place the spirit-level mid-way between the two stations, and consider the difference of the readings on the levelling-staff, as showing the true difference of level between the two stations.



Suppose it were required to find the difference of level between two points, G and H, in the adjoining figure; let A B represent a portion of the earth's surface, C the centre, and C G, C I, and C H, radii of the earth. Now a spirit-level being set up and adjusted at I, an observer looking through the telescope would see objects in the direction of the horizontal line, D E, only, and a staff held upright at H would be read off in the point, E, on the horizontal line; but this point is higher than the true level, by the distance, H E, which is the correction for curvature due to the distance, I H (see page 259): if that quantity be subtracted from the reading of the staff, the remainder will show the difference of level between the points I and H. If the same process be gone through, by holding a staff at G, then the difference of level between G and I will also be ascertained, which, being compared with the former difference, will show how much higher one of the points, G or H, is above the other; but it must be evident that, if G and A be equally distant from I, the horizontal line, D E, being a tangent at the middle point, I, must cut the staff at D on the same level with the point, E; that is, C D is equal to C E, therefore D and E are level points, being equi-distant from the centre of the earth, and if the reading of one staff above the ground is greater than the reading of the other, the difference will at once show the variation of level between the points where the staves were held, viz., G and H: the effect of curvature is thus removed by *simply placing the instrument mid-way between the station-staves.* The effects of the atmospheric refraction will likewise be done away with in the same process, because it will affect both observations alike unless under peculiar circumstances of the weather, &c., over which the observer has no control.

I scarcely need remind my reader that, should he have occasion to perform a levelling operation in which his spirit-level will be placed at one of the stations, instead of standing mid-way between them, and if great exactness is required, he must apply the proper corrections for curvature and refraction to all distances exceeding 1000 feet.

TABLE *for determining Altitudes by the Barometer. Computed by* SAMUEL B. HOWLETT, *Chief Draftsman, Ordnance, from the formula given by* F. BAILY, ESQ.

Thermometers to the Barometers.			Thermometers in the open air.								Latitude of the place.	
D.	B. Thermometer highest at lowest station.	B. Thermometer lowest at lowest station.	S.	A.	S.	A.	S.	A.	S.	A.	L.	C.
			40°	4·7689067	75°	4·7859208	110°	4·8022936	145°	4·8180714	0°	0·0011689
			41	·7694021	76	·7863973	111	·8027525	146	·8185140	3	·0011624
			42	·7698971	77	·7868733	112	·8032109	147	·8189559	6	·0011433
0°	0·0000000	0·0000000	43	·7703911	78	·7873487	113	·8036687	148	·8193975	9	·0011117
1	·0000434	9·9999566	44	·7708851	79	·7878236	114	·8041261	149	·8198387	12	·0010679
2	·0000869	·9999131	45	·7713785	80	·7882979	115	·8045830	150	·8202794	15	·0010124
3	·0031303	·9998697	46	·7718711	81	·7887719	116	·8050395	161	·8207196	18	·0009459
4	·0001737	·9998262	47	·7723633	82	·7892451	117	·8054953	152	·8211594	21	·0008689
5	·0002171	·9997828	48	·7728548	83	·7897180	118	·8059509	153	·8215988	24	·0007825
6	·0002605	·9997393	49	·7733457	84	·7901903	119	·8064058	154	·8220377	27	·0006874
7	·0003039	·9996959	50	·7738363	85	·7906621	120	·8068604	155	·8224761	30	·0005848
8	·0003473	·9996524	51	·7743261	86	·7911335	121	·8073144	156	·8229141	33	·0004758
9	·0003907	·9996090	52	·7748153	87	·7916042	122	·8077680	157	·8233517	36	·0003615
10	·0004341	·9995655	53	·7753042	88	·7920745	123	·8082211	158	·8237888	39	·0002433
11	·0004775	·9995220	54	·7757925	89	·7925441	124	·8086737	159	·8242256	42	·0001223
12	·0005208	·9994785	55	·7762802	90	·7930135	125	·8091258	160	·8246618	45	·0000000
13	·0005642	·9994350	56	·7767674	91	·7934822	126	·8095776	161	·8250976	48	9·9998775
14	·0006076	·9993916	57	·7772540	92	·7939504	127	·8100287	162	·8255331	49	·9998372
15	·0006510	·9993481	58	·7777400	93	·7944182	128	·8104795	163	·8259680	50	·9997967
16	·0006943	·9993046	59	·7782256	94	·7948854	129	·8109298	164	·8264024	51	·9997566
17	·0007377	·9992611	60	·7787105	95	·7953521	130	·8113796	165	·8268365	52	·9997167
18	·0007810	·9992176	61	·7791949	96	·7958184	131	·8118290	166	·8272701	53	·9996772
19	·0008244	·9991741	62	·7796788	97	·7962841	132	·8122778	167	·8277034	54	·9996381
20	·0008677	·9981305	63	·7801622	98	·7967493	133	·8127263	168	·8281362	55	·9995995
21	·0009111	·9990870	64	·7806450	99	·7972141	134	·8131742	169	·8285685	56	·9995613
22	·0009544	·9990435	65	·7811272	100	·7976784	135	·8136216	170	·8290005	57	·9995237
23	·0009977	·9990000	66	·7816090	101	·7981421	136	·8140688	171	·8294319	58	·9994866
24	·0010411	·9989564	67	·7820902	102	·7986054	137	·8145153	172	·8298629	59	·9994502
25	·0010844	·9989129	68	·7825709	103	·7990681	138	·8149614	173	·8302937	60	·9994144
26	·0011277	·9988694	69	·7830511	104	·7995303	139	·8154070	174	·8307238	63	·9993115
27	·0011710	·9988258	70	·7835306	105	·7999921	140	·8158523	175	·8311536	66	·9992161
28	·0012143	·9987823	71	·7840098	106	·8004533	141	·8162970	176	·8315830	69	·9991293
29	·0012576	·9987387	72	·7844883	107	·8009142	142	·8167413	177	·8320119	75	·9989852
30	·0013009	·9986952	73	·7849664	108	·8013744	143	·8171852	178	·8324404	81	·9988854
31	·0013442	·9986516	74	·7854438	109	·8018343	144	·8176285	179	·8328686		

Make $R = \log. \beta - (B + \log. \beta'.)$

The log. diff. of altitude in English feet $= A + C + \log.$ of R.

$\beta' =$ height of the barometer at the upper station.

$\beta =$ height of the barometer at the lower station.

$S =$ sum of the detached thermometers at the two stations.

$D =$ difference of the attached thermometers at the two stations.

$L =$ latitude of the place of observation.

The degrees of temperature according to Fahrenheit.

$A = \log. \{60345{\cdot}51 \times [1 + {\cdot}00111111 \ (t + t' - 64^\circ)]\}$

$B = \log. \{1 + {\cdot}0001 \ (T - T')\}$

$C = \log. \{1 + {\cdot}002695 \ \cos. 2\phi\}$

$\phi =$ the latitude of the place of observation.

$\left.\begin{array}{l} T = \text{the temperature of the mercury} \\ t = \text{the temperature of the air.....} \end{array}\right\}$ at the lower station.

$\left.\begin{array}{l} T' = \text{the temperature of the mercury} \\ t' = \text{the temperature of the air.....} \end{array}\right\}$ at the upper station.

DIRECTIONS FOR USING THE FOREGOING TABLE.

To the log. of the height of barometer at the upper station, add the number from the proper column in B, opposite the difference of the degrees read on the attached thermometers at the two stations, and subtract their sum from the log. of the height of the barometer at the lower station, and call this result R; then to the log. of R add the number in A opposite the sum of the degrees read on the detached thermometers at the two stations, and also add the number in C, opposite the latitude of the place, and the sum, rejecting the tens from the index, will be the log. difference of altitude in feet.

Example I.

Station.	Barometer.	Attach. Ther.	Detach. Ther.
Lake..	29·950	50°	49°
Mountain.	27·474	44	45
Latitude 55°....			

Log. of 27·474......1·4389219
B...50° − 44° = 6°..0·0002605

1·4391824
Log. of 29·950......1·4763968

R. ....0·0372144

Log. of R ....8·5707110
A..49° + 45° = 94°..4·7948854
C..55° ....9·9995995

Log. diff. of altitude..3·3651959 = 2318·44 feet.

Example II.

Station.	Barometer.	Attach. Ther.	Detach. Ther.
Wharf	29·799	39°	37°·5
Hill	29·384	45	46 ·0
Latitude 51° 30′			

Log. of 29·384......	1·4681109
B..45° — 39° = 6° ..	9·9997393
	1·4678502
Log. of 29·799......	1·4742017
R.................	0·0063515
Log. of R	7·8028763
A 46°+37°·5=83°·5 .	4·7899541
C 51° 30′	9·9997367
Log. diff. of altitude..	2·5925671 = 391·35 feet.

The most approved mountain barometer is that of the eminent French philosopher, Monsieur Guy-Lusac; which consists of a small glass syphon tube, enclosed in a brass one, of about 5-8ths of an inch diameter, which is graduated, and provided with two verniers, by means of which the length of the mercurial column may be read off at once to 5-100ths of an inch. A thermometer is attached, the bulb of which passes through the brass tube, and touches the glass one. The whole goes into a leathern case, little larger than a stout walking cane; which, being lined with tin, affords an excellent protection to the instrument. A common gimlet accompanies the barometer, to serve as a hook upon which to suspend it when in use.

The great superiority of this construction consists in the extreme portability of the instrument, which has only to be reversed—that is, turned over end,—and kept in a nearly upright position; and it may be carried from place to place with perfect safety, moderate care being used.

Messrs. Troughton and Simms have improved upon the French construction, by placing the zero at the bottom of the scale, causing both verniers to read upwards; instead of having it in the middle, which occasions the readings to be contrary ways, and likely to be productive of error. Colonel Mudge used this barometer extensively in his survey of the north-east boundary in America; and, as I am informed, pronounced very favourably with respect to its merits.

LATITUDE AND LONGITUDE.

OF FINDING THE LATITUDE.—LONGITUDE.—DESCRIPTION AND USE OF THE SEXTANT.—ITS ADJUSTMENTS.

It is very desirable that military men should be acquainted with the ordinary methods of determining latitude and longitude; by which they will often be enabled to render valuable additions to our geographical knowledge.

There is no doubt that over most parts of the globe, lines of coast generally, together with remarkable points situated thereon, are traced upon maps and charts with much accuracy, owing to the professional exertions of our naval brethren; but, beyond the confines of Europe, we have reason to believe that the courses of some of the greatest rivers, as well as the positions of many cities and towns, have been laid down on very loose authority.

Now, it must be admitted that officers, both of the Royal Army and East India Company's service, have greater opportunities than most persons of observing and correcting the errors of maps, whether their wanderings into remote regions are occasioned by the calls of professional duty, or proceed from the spirit of enterprise so prevalent amongst them, which impels so many to travel.

The latitude of a place may be obtained by the simplest of all astronomical observations, namely, that of taking a meridian altitude of the sun with a sextant; then, with a few necessary corrections, and the sun's declination being given, the latitude is found by a mere addition or subtraction, as the case may require.

As regards the longitude, the method most generally practised of obtaining it is by what is called a lunar observation; which is simply to measure very accurately the distance between the sun and moon, or between the moon and a star, when those objects are above the horizon, and within distance; that is, within the limits that a sextant will measure, namely to 120 degrees.* The altitudes of the sun and moon are to be taken at the same instant, and the apparent time at the moment of observation is to be noted by means of a watch, whose error has been previously ascertained by an observation. With these data, and a rule for the necessary calculation, aided by certain tables, any person acquainted with arithmetic and logarithms may work out the longitude;

* Observations, both for the latitude and longitude, are as easily made by means of a star, as by the sun. For an *altitude* of the sun, or that of a star, a pocket-sextant may suffice; but in taking a *lunar*, as the accuracy of result depends upon the exactness with which the distance between the sun and moon, or the latter and a star, is measured, a larger sextant is necessary.

thus dispensing with all knowledge of Geometry, Trigonometry, or Astronomy, and of course of any acquaintance with the principle upon which the calculation proceeds. In this way I have seen commanders, and mates of transports and merchant-vessels, men possessed of little more than such practical education as is to be acquired on board ship, bring out the longitude to within 10 or 12 miles.

Here we have an instance of the vast importance of science to the concerns of life. The astronomer, acquainted with the moon's rate of motion, has deduced from it a method of finding what o'clock it is at two places situated under different meridians at the same instant of time; while the mathematician furnishes us with formulæ and tables, by means of which an intelligent ship-boy is soon taught how to ascertain his vessel's longitude as well as it could be found by the man of science himself.

OF FINDING THE LATITUDE.

The latitude of a place is its distance from the equator, either north or south, and is measured by an arc of a meridian contained between the zenith and the equinoctial; hence, if the distance of any heavenly body from the zenith when on the meridian, and its declination, or number of degrees and minutes it is to the northward or southward of the equinoctial, be given, the latitude may then be obtained.

The meridian zenith distance of an object is found either from its altitude taken when on the meridian, or from one or two altitudes observed when out of the meridian.

Altitudes of the sun and moon taken on land require in strictness three corrections, in order to obtain the true altitude of their centres, to which all astronomical calculations respecting the heavenly bodies are adapted; these are for semi-diameter, refraction, and parallax.* (See page 118, and following.) In taking an altitude of the sun, by means of a sextant and an artificial horizon (page 115), either the upper or lower limb may be used; if the former be taken, and the contact formed, as noticed at page 117, it is evident that a quantity equal to the semi-diameter of the sun must be added to the observed altitude, to give the altitude of his centre. But if the altitude of the upper limb be taken, the semi-diameter of the sun must be subtracted.

To find the latitude of a place by a meridian altitude of the sun.

Rule. To the observed altitude of the sun's lower limb add the sun's semi-diameter (16 minutes);† but if the upper limb be observed,

* Parallax being only a few seconds, is usually omitted in observations of this kind.

† The semi-diameter of 16′ is taken as a mean: it depends on the distance of the sun from the earth.

subtract it, and the sum or remainder will be the apparent altitude of the sun's centre.

From the apparent altitude of the sun's centre subtract the refraction answering to that altitude, and the remainder will be the true altitude of of the sun's centre.

Subtract the true altitude of the sun's centre from 90°, and the remainder will be the sun's true meridian zenith distance, which is to be called north or south according as the observer is north or south of the sun at the time of observation.

Take the sun's declination, and reduce it to the meridian of the place (when the longitude is considerable), noting whether it be north or south. Then, if the zenith distance and declination be both north or both south, add them together; but if one be north and the other south, subtract the less from the greater, and the sum or difference will be the latitude, of the same name with the greater.*

Example I.

June 18th, 1828, the meridian altitude of the sun's lower limb was 43° 18′, the observer being north of the sun; required the latitude of the place of observation.

* The Nautical Almanac, some books on navigation, White's Ephemeris, and others, contain the tables of refraction, parallax, declination, correction for longitude, &c.

Obs. alt. sun's lower limb. . .	43°	18′
Sun's semidiameter.	+	16
Apparent alt. sun's centre. . .	43	34
Refraction	−	1
True alt. sun's centre.	43	33
	90	0
Sun's zenith distance.	46	27 N.
Sun's declination	22	26 N.
Latitude. . . .	69	53 N.

EXAMPLE II.

September 21st, 1829, in longitude 60° E., the meridian altitude of the sun's lower limb was 56° 26′, the observer being north of the sun, required the latitude of the place.

Obs. alt. sun's lower limb. . .	56°	26′
Semidiameter	+	16
App. alt. sun's centre.	56	42
Refraction	−	1
True alt. sun's centre.	56	41
	90	0
Sun's zenith distance.	33	19 S.
Sun's declination . . 0° 44′ } Corr. for longitude + 4 }	0	48 N.
Latitude. . . .	32	31 S.

OF FINDING THE LONGITUDE.

A variety of methods have been proposed for determining the longitude of a place, but almost all of them depend upon one general principle — namely, the comparison of the relative times under two different meridians; so that, if the time under a given meridian be known, and also the time under any other meridian, the difference of these times turned into degrees and minutes, in the proportion of 15 degrees to 1 hour, will be the difference of longitude between the two meridians. For as the sun *apparently* moves round the earth, from east to west, in 24 hours, or over an arc of 15 degrees of the equator in one hour of time, all places lying to the eastward of any meridian, will have noon sooner — or, if to the westward, later — by as much time as the sun takes to pass from the meridian of one place to the meridian of the other: hence, if the time at the meridian of Greenwich (from whence the longitude is reckoned), and of any other place, at the same moment of absolute time, be given, its longitude from Greenwich may be inferred by reducing the difference of times into degrees and minutes, in the proportion of 15 degrees of longitude to 1 hour of time: moreover, if the time at the place be greater than that at Greenwich, its longitude will be east; but if less, it will be west. Thus, suppose it is ascertained that the time at Greenwich is 2 hours past noon, when it is just noon at the ship; it will thence appear that the longitude of the ship is 30 degrees west of the meridian of Greenwich, because the sun passes over 30 degrees of the equator in 2 hours of time; and having left the meridian of Greenwich 2 hours since, the ship must consequently be to the westward of that meridian. If we suppose the time at the ship to be 4 hours past noon, its longitude would be 30 degrees east of Greenwich, for the sun, in this case, would have passed the meridian of the ship 2 hours before it passed that of Greenwich.

Now, the time at any given meridian may be easily computed by an altitude of the sun or a star, taken when distant from the meridian, or from observations of the sun when at equal altitudes; and the time at Greenwich may be ascertained by means of a time-keeper, or by various astronomical observations. With respect to the first of these, it is obvious that, if a clock or watch could be so constructed as to go uniformly in all seasons and at all places, such a machine being once set to the time at Greenwich would always show the real time at Greenwich, in whatever part of the earth it might be; and, therefore, when the time under any other meridian was found, and compared with that shown by the time-keeper, the longitude of the place from Greenwich would be readily obtained. To effect this purpose several ingenious artists have exerted their abilities, and have brought time-keepers to an astonishing degree of perfection; whereby they have become a valuable acquisition to the navigator, in determining the difference of longitude made in short periods: however, considering the delicacy of their construction, and the various accidents to which they are liable, an implicit confidence ought not to be placed in them, particularly during long voyages; but recourse should be had to astronomical observations, whenever opportunities present themselves.

The various astronomical methods of determining the longitude depend likewise upon the above-mentioned general principle; for, by observing the time at the meridian of a given place when any celestial appearance happens, and comparing the same with the time at Greenwich, shown by the Nautical Almanac,* their difference, reduced to degrees

* The Nautical Almanac is published annually, by order of the Lords Commissioners of the Admiralty, generally four years forward, and contains 22 pages to each month; in these are entered the sun's longitude, right ascension, declination; the planets' longitudes, latitudes, times of passing the meridian; the times of solar and lunar eclipses, together with those of Jupiter's satellites; the distance of the moon from the sun and certain fixed stars, at the beginning of every third hour; and in general the times when any remarkable appearance takes place, being all computed for Greenwich time. This excellent and most useful work was originally proposed by, and calculated and printed under the immediate inspection of, the late Dr. Maskelyne, Astronomer Royal; and has recently been very much improved and enlarged.

and minutes, gives the longitude as before. Suppose, for instance, that an eclipse of the moon should be observed at a certain place to begin at midnight, and that by the Almanac the time at Greenwich, when the eclipse commenced, was three hours past midnight; now, as the commencement of the eclipse must be seen at the same moment of absolute time in all parts where it is visible, the difference between the time at the place of the observer and that of Greenwich, which is three hours, and answers to 45 degrees, must be the longitude of the place; and it is evidently west, because the time at the place is less than the time at Greenwich. Upon the same principle the eclipses of Jupiter's satellites will give the longitude. But eclipses of the moon happen too seldom to be of use at sea, and the satellites of Jupiter are visible only through a telescope of considerable magnifying power.

The most practical method of finding the longitude, by celestial observations, is that of measuring the angular distance between the moon and sun, or the moon and certain stars near the ecliptic, usually called a *lunar observation.* The moon describes every month an orbit round the earth from west to east, at the distance of about 240,000 miles; in appearance it moves on the celestial concave in a curve line, near the ecliptic or apparent orbit of the sun. It moves faster than the sun from west to east, by about a degree and a half in three hours. Supposing it to be at the distance of from about 30° to 120° from the sun, either west or east of it, we are frequently enabled to see the two bodies above the horizon at the same time. When this is the case, the distance of the two bodies may be observed with a sextant, and thence the correct distance of their centres, as seen from the earth's centre, which is called their true distance, may be computed. And from this true distance, with the help of the Nautical Almanac, wherein the true distance (within certain limits) is put down for every third hour, Greenwich apparent time may be easily determined.

In favourable weather distances may be taken at all times, when the objects are more than four or five degrees above the horizon, except about the time of new moon; and as the moon's daily motion is about 13 degrees, or at the rate of 1 minute of a degree in 2 minutes of time, if her true angular distance from the sun or a star can be ascertained within 30 seconds of a degree, the corresponding time at Greenwich will be known within 1 minute of time, and hence the longitude within 15 minutes of a degree.

To facilitate this important problem, the true angular distances of the moon from the sun, or a fixed star,* are set down in the Nautical Al-

* The stars used in the Nautical Almanac for the above purposes are, *α Arietis, Aldebaran, Pollux, Regulus, Spica Virginis, Antares, α Aquilæ, Fomalhaut,* and *α Pegasi.* As a

manac for the beginning of every third hour of Greenwich time; and the time answering to any intermediate distance may be found by proportional parts: hence, the distance between these objects being taken with a sextant, and the corresponding time at Greenwich found by the Almanac, and compared with the time at the ship, their difference will be the longitude of the place of observation.

But before the observed distance is compared with those in the Almanac, it must be corrected, in order to find the true distance; for, by the effects of parallax and refraction, the moon is always seen lower than its true place, and the sun or star higher: hence the true distance is almost always greater or less than the observed.

In taking a *lunar observation*, two assistants should be employed to observe the altitudes of the objects while the principal observer is taking their distance; also one with a watch to mark the times when the observations are made. If the sun or star be at a proper distance from the meridian, the time may be inferred from its altitude, but if it be too near the meridian a watch will be absolutely

knowledge of these stars is of great importance to the observer, Celestial Maps, with directions for using them, have been published; in which the above stars are particularly pointed out, and may be more readily known by comparing the maps with the heavens than they possibly can by any verbal description. To be had of J. W. Norie and Co., 157, Leadenhall-street.

necessary; whose error must be found by an altitude taken before or after the lunar observation, according as it may be most convenient.

The sextants being properly adjusted, and their index errors found, place the assistants in the most convenient situation, and let the one holding the watch be provided with a paper and pencil, to note down the observations when taken: all things being ready, proceed to take the distance between the objects, the assistants at the same time observing the altitudes of each; when this is done, give notice to the assistant with the watch, who is to mark the exact time and set it down, together with the observations read off from the instruments; in this manner proceed four or five times, each set of observations being noted down in proper order: then take the mean of the times and of each observation, by adding them together and dividing their sum by the number of sets observed, the quotient will give the mean of each set, which is much more to be depended upon than if one set only were taken.

Method of observing when the altitudes and distance are taken at the same instant, and the apparent time at the place of observation is obtained from the altitude of the sun or a star.

For the sun and moon. When the sun and moon are both above the horizon, and within distance (that is, when their distance is put down in the Nautical Almanac), bring with the sextant the darkened image of the sun to the moon, without using a telescope; when this is done clamp the index-plate, put in and adjust the telescope; then by means of the tangent-screw make an exact contact of the nearest limbs.

For a star and the moon. Bring the image of the moon (darkened if necessary) up to the star; clamp the index-plate, put in the telescope and adjust it; then make the enlightened limb of the moon pass through the middle of the star by means of the tangent-screw.

The following is the usual method of taking down a set of lunar distances, with the altitudes of the objects observed at the same time, and of finding the mean observed distance and altitudes:—

	Times per watch.	Distances sun and moon.	Alts. sun's lower limb.	Alts. sun's upper limb.	
	3 0 16	91 19 10	37 58	49 58	
	1 25	19 40	37 43	50 15	
	3 10	20 20	37 20	50 28	
Divide by 3	4 51	59 10	121	51	sums.
Means.....	3 1 37	91 19 43	37 40⅓	50 17	
Index errors		+ 2 50	− 1	0	
Observed dist. and alts...		91 22 33	37 38⅓	50 17	

When assistance cannot be obtained, one person may take a set of observations, in the following order, noting the times by a watch:—1, the altitude of the sun or star; 2, the altitude of the moon; 3, any number of distances; 4, the altitude of the moon; 5, the altitude of the sun or star. Then add together the distances, and the times when they were taken, each of which being divided by the number observed, will give the mean time and distance: then to reduce the altitudes to the mean time, say, as the difference of times between the observations is to the difference of their altitudes, so is the difference between the time that the first altitude was taken and the mean time, to a fourth number; which, added to, or subtracted from, the first altitude, according as it is increasing or decreasing, will give the altitude reduced to the mean time.

Example.

Suppose the following observations were taken at the under-mentioned times: required the altitudes of the sun and moon reduced to the mean time and distance.

	Times by watch. h	m	s		°	′	″	
	3	25	41	Alt. sun's lower limb...54	5	0		
		28	44	Alt. moon's upper limb 20	3	0		
Mean time. 3, 33 47		32	50	Dist. nearest limbs.....73	13	30	Mean dist. 73 14 3
		33	30	Dist. nearest limbs.....73	14	10	
		35	0	Dist. nearest limbs.....73	14	30	
		38	20	Alt. moon's upper limb 20	45	0		
		42	4	Alt. sun's lower limb...53	14	0		

	Times.	Altitudes.	Times.	
	h m s	° ′	h m s	
1st alt.	3 25 41	54 5	3 25 41	1st altitude.
2nd alt.	3 42 4	53 14	3 33 47	mean time.
Diff.	16 23 :	51 ::	8 6 :	0° 25′ 13″

First altitude of sun's lower limb 54 5 0

Reduced altitude of sun's lower limb... 53 39 47

	Times.	Altitudes.	Times.	
	h m s	° ′	h m s	
1st alt.	3 28 44	20 3	3 28 44	1st altitude.
2nd alt.	3 38 20	20 45	3 33 47	mean time.
Diff.	9 36 :	42 :	5 3 :	0° 22′ 6″

First altitude of moon's upper limb 20 3 0

Reduced altitude of moon's upper limb .. 20 25 6

Hence we obtain the following set of observations:—

Time by watch.	Dist. near limb of sun and moon.	Alt. sun's lower limb.	Alt. moon's upper limb.
h m s	° ′ ″	° ′ ″	° ′ ″
3 33 47	73 14 3	53 39 47	20 25 6

The lunar method of finding the longitude requires the utmost exactness on the part of the observers, otherwise a considerable error will be made. The moon moves, as before noticed, at the rate of about a degree in two hours, or one minute of space in two minutes of time. Therefore, if we make an error of one minute in observing the distance between the sun and moon, or between the moon and a star, we make an error of two minutes in time, or thirty miles in longitude at the equator.

The necessary tables for working out astronomical observations have been brought to great perfection. Such plain rules, also, are given in some of the best treatises on navigation, that any one tolerably versed in arithmetic, will find no difficulty in the computations.

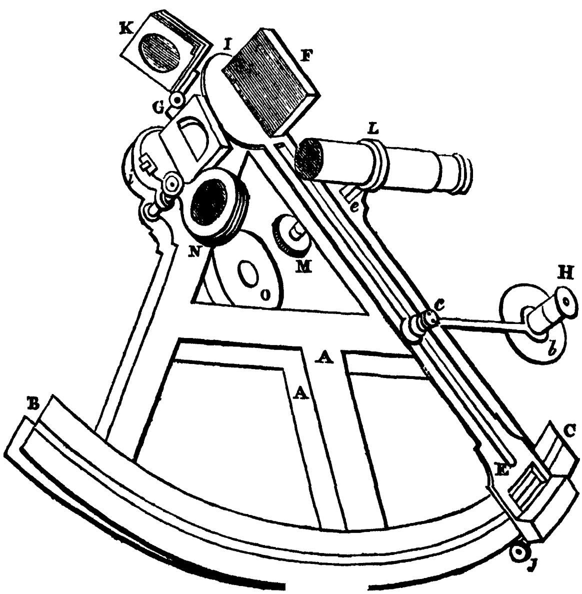
A great variety of methods of working out lunar observations will be found in the numerous books on navigation that have been published. Thomson's Lunar and Horary Tables are much valued by nautical men, and perhaps his rules may be considered the most simple of any. Norie's Complete Epitome of Practical Navigation is a very good work: the student will there find numerous examples of ascertaining latitude and longitude, with the requisite tables for working out astronomical observations, preceded by a copious explanation of each Table. In this work, however, there is a vast deal of matter which we do not require, and is, therefore, an encumbrance. It is to be regretted that no work on a similar plan, and divested of all information that is purely nautical, exists: but with the very limited demand for such a book, no one would willingly risk its publication.

I did entertain some thoughts of adding to my work full instructions for finding the latitude by meridian, and double altitudes of the sun, and by altitudes of the moon, stars, &c.; and of finding the longitude by lunar observation; giving also a set of logarithmic tables, together with all the tables required in working a lunar observation: but uncertain whether so great an addition to the book would be considered desirable by officers generally, I have thought it better to relinquish this plan; and refer those persons who may wish for such information to the nautical works above-mentioned, and the Rev. J. Cape's valuable Tables, more recently published.

DESCRIPTION AND USE OF THE SEXTANT.

The large sextant differs both in form and in its adjustments from the pocket box-sextant, which has been noticed at page 98; and I am induced to add a description of it in this place, being one of the most valuable instruments we possess: I cannot do better than take this principally from Mr. Simms' work on Mathematical and Astronomical Instruments.

The annexed figure represents a sextant of Troughton's construction, having a double frame, A A, connected by pillars, thus uniting strength with lightness. The arc, B C, is generally graduated to 10 minutes of a degree, commencing near the end C, and it is numbered towards B. The divisions are also continued on the other side of zero, towards C, forming what is called the arc of excess, which is useful in determining the index-error of the instrument, as will be explained hereafter. The limb is subdivided by the vernier, E, into 10″, the half of which (or 5″) can be easily estimated: this small quantity is easily distinguishable by the aid of the microscope, H, and its reflector, *b*, which are connected by an arm with the index, I E, at the point, *c*, round which it turns as a centre, affording the means of examining the whole vernier, the connecting arm being long enough to allow the microscope to pass over the whole of it.



To the index is attached a clamp, to fasten it tc the limb, and a tangent-screw, J (in the figure the clamp is concealed from view), by which the index may be moved any small quantity, after it is clamped, to render the contact of the objects observed more perfect than can be done by moving it with the hand alone. The upper end, I, terminates in a circle, across which is fixed the silvered index-glass, F, over the centre of motion, and perpendicular to the plane of the instrument. To the frame at G is attached a second glass, called the horizon-glass, the lower half of which only is silvered: this must likewise be perpendicular to the plane of the instrument, and in such a position that its plane shall be parallel to the plane of the index-glass, F, when the vernier is set to 0° (or zero) on the limb, B C. A deviation from this position constitutes the index-error, before spoken of.

The telescope is carried by a ring, L, attached to a stem, *e*, called the up-and-down piece, which can be raised or lowered, by turning the milled-screw, M: its use is to place the telescope so that the field of view may be bisected by the line on the horizon-glass, that separates the silvered from the unsilvered part. This is important, as it renders the object seen by reflection, and that by direct vision, equally bright: * two telescopes, and

* This is not the case when one object is much brighter than the other, as the sun and moon; in taking the distance between

a plain tube, all adapted to the ring, L, are packed with the sextant, one showing the objects erect, and the other inverting them; the last has a greater magnifying power, showing the contact of the images much better. The adjustment for distinct vision is obtained by sliding the tube at the eye-end of the telescope in the inside of the other: this also is the means of adapting the focus to suit different eyes. In the inverting telescope are placed two wires, parallel to each other, and in the middle of the space between them the observations are to be made, the wires being first brought parallel to the plane of the sextant, which may be judged of with sufficient exactness by the eye. When observing with the telescope, it must be borne in mind, that the instrument is to be moved in a contrary direction to that which the object appears to take, in order to keep it in the field of view.

Four dark glasses, of different depths of shade and colour, are placed at K, between the index and horizon-glasses; also three more at N, any one or more of which can be turned down to moderate the intensity of the light, before reaching the eye, when a very luminous object (as the sun) is observed. The same purpose is effected by fixing a dark glass to the eye-end of the telescope: one

which, the screw, M, should be moved more than above stated, until they are both nearly of the same brightness, as an observation can be made better when this is the case, than when otherwise.

or more dark glasses for this purpose generally accompany the instrument. They, however, are chiefly used when the sun's altitude is observed with an artificial horizon, or for ascertaining the index-error; as employing the shades attached to the instrument for such purposes would involve in the result any error which they might possess. The handle, which is shown at O, is fixed at the back of the instrument. The hole in the middle is for fixing it to a stand, which is useful when an observer is desirous of great steadiness.

OF THE ADJUSTMENTS.

The requisite adjustments are the following:—the index and horizon-glasses must be perpendicular to the plane of the instrument, and their planes parallel to each other, when the index division of the vernier is at 0° on the arc; and the optical axis of the telescope must be parallel to the plane of the instrument. We shall speak separately of each of these adjustments.

TO EXAMINE THE ADJUSTMENT OF THE INDEX-GLASS.

Move the index forward to about the middle of the limb, then, holding the instrument horizontally with the divided limb towards the observer, and the index-glass to the eye, look obliquely down the glass, so as to see the circular arc by direct view and by reflection, in the glass at the same time; and if they appear as one continued circle, the index-glass is in adjustment. If it requires correcting, the arc will appear broken where the reflected and direct parts of the limb meet. This, in a well-made instrument, is seldom the case unless the sextant has been exposed to rough treatment; as the glass is, in the first instance, set right by the maker and firmly fixed in its place, and, its position not being liable to alter, no direct means are supplied for its adjustment.

TO EXAMINE THE HORIZON-GLASS AND SET IT PERPENDICULAR TO THE PLANE OF THE SEXTANT.

The position of this glass is known to be right when, by a sweep with the index, the reflected image of any object passes exactly over or covers its image as seen directly; and any error is easily rectified by turning the small screw, *i*, at the lower end of the frame of the glass.

TO EXAMINE THE PARALLELISM OF THE PLANES OF THE TWO GLASSES, WHEN THE INDEX IS SET TO ZERO.

This is easily ascertained; for, after setting the zero on the index to the zero on the limb, if you direct your view to some object, the sun for instance, you will see that the two images (one seen by direct vision through the unsilvered part of the horizon-glass, and the other reflected from the silvered part) coincide or appear as one, if the glasses are correctly parallel to each other; but if the two images do not coincide, the quantity of their deviation constitutes what is called the index-error. The effect of this error on an angle measured by the instrument is exactly equal to the error itself; therefore, in modern instruments, there are seldom any means applied for its correction, it being considered preferable to determine its amount previous to observing, or immediately after, and apply it with its proper sign to each observation. The amount of the index-error may be found in the following manner:—clamp the index at about 30′ to the left of zero, and, looking towards the sun, the two images will appear either nearly in contact or overlapping each other; then perfect the contact, by moving the tangent-screw, and call the minutes and seconds denoted by the vernier, the reading *on the arc.* Next place the index about the same quantity to the right of zero, or on the arc of excess, and make the contact of the two images perfect as before, and call the minutes and seconds on the arc of excess,* the reading *off the arc*, and half the difference of these numbers is the index-error; additive when the reading on the arc of excess is

* When reading off the arc of excess the vernier must be read backwards, or from its contrary end.

greater than that on the limb, and subtractive when the contrary is the case.

EXAMPLE.

Reading on the arc	31′	56″
Reading off the arc	31	22
Difference......	0	34
Index error	0	17

In this case, the reading on the arc being greater than that on the arc of excess, the index-error, = 17″, must be subtracted from all observations taken with the instrument, until it be found, by a similar process, that the index-error has altered. One observation on each side of zero is seldom considered enough to give the index-error with sufficient exactness for particular purposes; it is usual to take several measures each way, and half the difference of their means will give a result more to be depended on than one deduced from a single observation only on each side of zero. A proof of the correctness of observations for index-error is obtained by adding the above numbers together and taking one-fourth of their sum, which should be equal to the sun's semi-diameter as given in the Nautical Almanac. When the sun's altitude is low, not exceeding 20° or 30°, his horizontal, instead of his perpendicular, diameter should be measured (if the observer intends to compare with the Nautical Almanac, otherwise there is no necessity); because the refraction at such an altitude affects the lower part (or limb) more than the upper, so as to make his perpendicular diameter appear less than his horizontal one, which is that given in the Nautical Almanac: in this case the sextant must be held horizontally.

TO MAKE THE LINE OF COLLIMATION OF THE TELESCOPE PARALLEL TO THE PLANE OF THE SEXTANT.

This is known to be correct when the sun and moon, having a distance of 90° or more, are brought into contact just at the wire of the telescope which is nearest the plane of the sextant, fixing the index and altering the position of the instrument, to make the objects appear on the other wire; if the contact still remains perfect, the telescope is in proper adjustment; if not, it must be altered by moving the two screws which fasten to the up-and-down piece the collar into which the telescope screws. This adjustment is not very liable to be deranged.

Having now gone through the construction and adjustments of the sextant, it remains to give some instructions as to the manner of using it. For the principle of the sextant see page 113.

It is evident that the plane of the instrument must be held in the plane of the two objects, the angular distance of which is required; in a vertical plane, therefore, when altitudes are measured—in a horizontal or oblique plane, when horizontal or oblique angles are to be taken. As this adjustment of the plane of the instrument is rather difficult and troublesome to the beginner, he need not be surprised nor discouraged, although his first attempts may not answer his expectations. The sextant must be held in the right hand, and as slack as is consistent with its safety, for in grasping it too hard, the hand is apt to be rendered unsteady.

When the altitude of an object, the sun for instance, is to be observed, the observer, having the sea horizon before him, must turn down one or more of the dark glasses or shades, according to the brilliancy of the object; and directing his sight to that part of the horizon immediately beneath the sun, and holding the instrument vertically, he must with the left hand lightly slide the index forward until the image of the sun, reflected from the index-glass, appears in contact with the horizon, seen through the unsilvered part of the horizon-glass. Then clamp it firm and gently turn the tangent-screw, to make the contact of the upper or lower limb of the sun and the horizon perfect, when it will appear a tangent to his circular disk.* If an

* If the observer knows his latitude approximately, he may find the meridional altitude nearly, to which he may previously set his instrument; when he will not only find his object more

artificial horizon is employed, the two images of the sun must be brought into contact with each other, the index-error is applied to the angle read off; half of this has then to be corrected, as we have seen under the head of artificial horizon, at page 115. When the sea-horizon is employed, a quantity must also be subtracted for the dip, occasioned by the height of the eye above the level of the sea, as in a ship; which is not required when the altitude is taken by means of an artificial horizon. Tables for all these corrections may be found in any modern work on navigation.

If the observer is ignorant of the precise moment of the objects being on the meridian, he should, by a slow and gradual motion of the tangent-screw, keep the observed limb in contact with the horizon as long as it continues to rise; and immediately on the altitudes appearing to diminish, cease from observing, and the angle then read on the instrument will be the meridian altitude.

After what has been advanced little need be said about observing lunar distances, whether of the moon and the sun, or the moon and a fixed star or planet, except that the instrument must

easily, but have only a small quantity to move the index to perfect the observation.

Take from the Nautical Almanac the declination of the object, and, if it be the same name with the latitude, add it to the co-latitude: if of a different name, subtract it: the sum or difference will be the meridian altitude.

be held in the plane of the two objects; and it is generally preferable to direct the telescope to the fainter object, particulary if a star, as it can be more easily kept in view when seen directly than it can when seen by reflection. If the brighter object is to the left, the sextant must be held with the face downwards.

The enlightened limb of the moon is always to be brought into contact with the sun or star, even though the moon's image is made to pass beyond the sun or star before the desired contact can be obtained.

Perhaps the best method of taking a lunar distance is, not to attempt to make the contact perfect by the tangent-screw, but, when the nearest limbs are observed, make the objects overlap each other a little when they are receding, or leave a small space between them when they are approaching; and wait till the contact is perfect, and the reverse when the furthest limbs are observed.

Of the sextant, it has been said, that it is in itself a portable observatory; and it is doubtless one of the most generally useful instruments that has ever been contrived, being capable of furnishing data to a considerable degree of accuracy, for the solution of a numerous class of the most useful astronomical problems; affording the means of determining the time, the latitude and longitude of a place, &c., for which, and many other purposes, it is invaluable to the traveller, the surveyor, and the navigator.

MILITARY RECONNOISSANCE.

OBSERVATIONS.—CAPTAIN W. C. MAYNE'S WORK.—ON EYE-SKETCHING. — ON EXAMINING AND REPORTING UPON ROADS. — FORM FOR AN ORDINARY REPORT UPON A ROAD.—REPORT ON THE ROAD FROM MALAGA TO GRANADA.—HEADS OF INSTRUCTION FOR RECONNOISSANCE IN GENERAL.

WHEN preparing a new edition of this work, it was my intention to have gone into considerable detail on the important subject of *Military Reconnoissance;* and in prosecution of this design, I directed my attention to various foreign publications, in order that I might be able to compare the theory and practice of French and German officers with our own: intending to deduce from the whole a practicable system applicable to all countries. For most writers, who have treated of reconnoissance, seem to have framed their views with reference to the states of Europe alone, which being all, more or less correctly, mapped, the labours of the Quarter-Master-General's department in European warfare, are limited in comparison with what they become in countries previously unexplored.

While thus engaged, I met with a book which in a great measure supersedes the necessity of my persevering in the plan I had adopted; and I have great pleasure in referring young officers to the valuable compilation of Captain William Colburn Mayne, entitled "Military Reconnoissance." I have not the honour of being known to that gentleman, but feel great pleasure in bearing testimony to the ability, research, and judgment he has evinced in his work: and, trusting he will not be offended by the juxtaposition, I recommend that it be bound with my own.

On the publication of the first edition of my book, I received numerous letters from officers versed in the subjects of which it treats; and trusting that he will pardon the liberty, I shall quote some passages from one with which I was honoured by a former commanding officer,* who served as Assistant-Quarter-Master-General to the cavalry in Spain, and afterwards in the Waterloo campaign. After passing an opinion upon my work, more favourable perhaps than it deserves, he remarks, "There may, however, be occasions when military sketches are hastily called for, that officers may find themselves at the moment unprovided with instruments. In such cases it is a great advantage to them if they have been instructed and accustomed to sketch by the eye, according to the principle and rules taught

* Major-General Lord Greenock, K.C.B., Commander of the Forces in Scotland.

by the late General Jarry,* and laid down in full detail in his lecture on military drawing.

"With the aid of a few points taken from a map of the country, if any such exists, or a knowledge of the distances between two or three places which come within the compass of the sketch, sketches may be obtained; which although at best much more imperfect than those more regularly surveyed; yet, if done with care and attention, are often quite sufficient for military purposes, and should, I think, receive a fuller notice when you publish a second edition."

Had I carried out my design of writing at large on military reconnoissance, I should have availed myself of General Jarry's labours, having in my possession a MS. copy of his lectures on military topography.

With reference to the method of sketching without instruments, recommended by General Jarry, I am bound to say a few words, in obedience to the suggestion contained in the above quotation.

If no general map exists of a country in which military operations are carried on, it becomes necessary to construct one; and when very great accuracy is not sought for — which, indeed, may almost always be dispensed with — this may be done with much rapidity. When time permits, a

* General Jarry was a talented Frenchman, who, many years ago, instructed the students at the senior department of the Royal Military College, in military surveying, &c.

base line and triangulation, by observing angles with a pocket-sextant, or taking bearings with a prismatic compass, offer the readiest means of accomplishing the object; but a loose kind of map, yet good enough for military purposes, may be made by a few experienced staff-officers in a quicker manner.

In a flat country, the villages are usually connected by roads running tolerably direct; and if the distances between any three forming a triangle, are obtained either from the inhabitants, or by riding from one to another, the relative situations of those places can be determined on paper. In a mountainous country it is much more difficult to determine such places for points, as roads generally take the most convenient rather than the shortest way of reaching any particular spot; so that two villages may lie six miles apart, reckoning by the road between them, while geographically they may not be half that distance from each other.

For eye-sketches of limited extent, it will always be found desirable to lay down a triangle, formed by three conspicuous objects as a basis, after which the filling in of the first triangle, and subsequent extention of the sketch, is not a task of difficulty to any one who has had much practice in rough military sketching. A right angle can be measured by the eye with tolerable accuracy; and objects, whose position is already ascertained, serve, either by getting them in a line with a point which it is desirable to fix, or by some such simple contrivance, to determine the situations of others. I do not, however, consider it requisite to enter into much detail respecting eye-sketching, as an officer of ability and resource can always devise, at the moment, some plan of proceeding more available, according to the circumstances in which he may be placed, than any writer on the subject can pretend to specify: and it may further be observed, that instruments, and the necessary apparatus for sketching, are all so portable, that an officer can rarely find himself reduced to the necessity of making any sketches of consequence without their aid; and should he accidentally be deprived of them, he has only to exert due care and intelligence to repair his misfortune by increased diligence and energy.

ON EXAMINING AND REPORTING UPON ROADS.

Examining and reporting upon roads is one of the most important duties of a staff-officer in the field; and no division, brigade, or even considerable detachment, should advance without being preceded by an intelligent officer, whose business it is to ascertain the nature and practicability of the route by which troops are to march. In a friendly country, and when the enemy is distant, he may be a day's march or more a-head of them; and, if accompanied by a couple of dragoons, can communicate when necessary with the rear. Under other circumstances, he may not be able to precede the march of the troops by more than an hour or two; but however short the time he may have for making observations, the officer in command will always find them of great value.

A knowledge of the main roads which traverse a country should first be acquired, and then attention must be given to the bye-roads and paths. In many countries, particularly in dry weather, it will often be found advantageous to abandon a narrow road, and guide the march of troops towards a given point by the most direct or most practicable course. An officer employed on this duty must make a rough sketch as he proceeds, by taking a succession of bearings, which he may plot at once in the manner shown in Section II.* He will be

* My own practice has generally been to plot the bearings at once, and to sketch in the road with accuracy, noting not only the houses upon it, but also such buildings of whatsoever nature as existed on each hand, to the distance of from a quarter to half a mile.

When serving on the staff in the Netherlands in 1814, the Quarter-Master-General of the Army, Sir Hudson Lowe, wished me to try a method of sketching that had been communicated to him, when in Egypt, by the late Major-General Beatson, of the Indian Army, which I shall briefly describe. Take half a quire of foolscap paper and double it lengthwise, the crease thus formed in the middle of the paper is then to be considered as representing the route; begin at the bottom of this crease, and note the first bearing taken, marking down all objects that present themselves either on the road or on either side of it, the same as if plotted to a scale; together with the careful to mark in his sketch the several streams that he finds in his progress, noting their width, depth, and the nature and dimensions of the bridges upon them; he will also observe whether timber is at hand, should it be requisite to construct temporary bridges. (In Spain and Portugal the beams, rafters, and floorings of the large *ventas*, or inns, often supplied the means of effecting this object.)

In examining roads great attention must be paid to the nature of the soil over which they pass, whether it is gravel, sand, or clay; and the materials of which a road is formed when much military traffic is expected along it, should be carefully noted, as the weight of artillery and stores soon destroy a road in autumn or winter, unless it have a foundation of stone or coarse gravel. The inhabitants of a country are little able to judge of the practicability of roads for military purposes, and

several distances from the first station to any bridge, house, road branching off, &c. On each side of the line representing the road a space is left, about one inch and a half wide, in which a view of the country, as seen from particular points, is given. I reconnoitred extensively in the Low Countries upon this principle, and can recommend it for a rapid reconnoissance; but, as the plan must afterwards be plotted for use, I rather give a preference to the mode of plotting in the field: still, it is often convenient to be unencumbered with a sketching-case, and in this way a few sheets of paper, which may be folded and put in the pocket, will answer our purpose.

their opinions must always be received with caution.*

I now present to the military student's attention two forms of report for routes, to be made use

* After the battle of Talavera, the British force found itself between two French armies, Soult having descended from the pass of Banos to the Tagus, and thus placed himself in a position to intercept the retreat of the British army by the bridge of Almaraz, while that of King Joseph, which had been defeated, lay in its front; the only retreat open to Sir Arthur Wellesley was across the Tagus, by the bridge of Arzobispo, into a country which the Spaniards, both military and civil, declared to be wholly impracticable for artillery. "Having well-weighed all the circumstances of his situation, which, to an ordinary mind, would have been one of great embarrassment, he unhesitatingly resolved on crossing the river—a decision to which he was prompted by the superior nature of his artillery; for, rugged and impassable as the country southward of the Tagus was reported to be, he well knew that British artillery officers would contrive means to carry their guns wherever a mule could find a footing. * * * * * The extreme heat of the weather, want of sufficient food, and the difficulties of the road, caused sufferings to the troops almost insupportable: but their energy triumphed. At one place, after crossing the Ibor, the guns were dragged up a mountain by the troops. When the Spaniards afterwards arrived at the same spot they abandoned their cannon in hopeless despair; and there it would have remained, had not Sir Arthur Wellesley succeeded by force of entreaty in prevailing upon them to follow the example of his own soldiers."—*Military Life of the Duke of Wellington, by Majors Basil Jackson and C. Rochfort Scott.*

In proof of the experience necessary, and caution to be exercised, when reporting upon a road, I will mention what occurred in the instance of a brother officer of mine:—he had described a certain bye-road or track, up the side of a of according to circumstances. The first is framed on the model of the one used in the Peninsular war, by officers of the Quarter-Master-General's department, under Sir George Murray.* This is such a report as any intelligent officer, who may have had the advantage of a military education, should be comptent to make; and without the information afforded by a report of this description, when circumstances permit of the necessary reconnoissance being made, no body of troops, as I have before observed, should move. A very exact delineation of the *ground* is not expected in the sketch which accompanies it, which is often hastily made while the troops are in movement; but all distances along the road must be given with as much accuracy as possible; and an individual employed on a duty of this nature must seek to procure the most accurate information

mountain in Portugal, as impracticable for artillery, when, to his amazement, he afterwards saw a battery of guns taken to the summit of the mountain by that track; but, to get them up, the artillerymen were actually compelled to support the wheels on the declivity side by means of handspikes; and it was only by wonderful exertion, prompted by the zeal of the British soldier, that the operation was effected. "I shall be very careful," said the officer in question to me, "how I again report a road as impracticable for artillery."

* The form annexed (No. 1), was drawn up at my request by Captain Hector Straith (author of the best works extant upon Fortification and Artillery), with a view to the instruction of the Cadets at the East India Military College. It is the result of his own observations when serving in India, is concise, and suited to the purpose.

respecting the roads and streams crossing, or which may run near to, the route upon which he is to report. Anything like a regular survey of the road is of course out of the question; but, by means of a prismatic-compass, bearings may be taken at every turning, and the distances along it being measured by the paces of a horse or otherwise, the road may be protracted at the moment, in the manner pointed out in Section II., with sufficient exactness. And in this way from twelve to fifteen miles of road, or the length of an ordinary march, can be carefully examined, and the ground on each side to a certain distance roughly sketched, in the course of a few hours.

It is desirable that sketches to accompany reports on roads should not be drawn to a smaller scale than *one inch to a mile;* yet at times, when such sketches comprise a great extent of road, or, as frequently happens, when two places of importance are connected by several roads, directed on different mountain-passes, fords, bridges, or intermediate towns, then a smaller scale may be adopted with advantage; since, in such cases, it is to be wished that the eye should embrace at one glance the whole extent of these various routes, as well as of any roads that may connect them transversely, and also the courses of the rivers and direction of the mountains that separate them.

The second form of report here given is intended to meet the foregoing circumstances; and

being necessarily of a more comprehensive character than the preceding, may be considered such a one as ought to be looked for from a Staff Officer. The map to accompany it should be obtained by a rapid triangulation, and the filling-in performed with great care; and, as in most cases, the scale must be far too small to admit of the ground being described with much detail, detached sketches of such portions of the different roads as present difficulties to the movements of troops, or as offer military positions, should be given on a larger scale.

A sketch of the nature of that given in the form, which comprises a considerable extent of mountainous country, requires some little time to execute; as the whole of the ground should be carefully gone over, and every pains taken to obtain an accurate knowledge of all its parts.* The report also, besides entering into a minute description of the country, to which it especially relates, should furnish good information respecting the communications with places at a distance, and

* I am indebted for this sketch and report to Major C. Rochfort Scott, late of the Royal Staff Corps, who reconnoitred and drew up detailed reports of a very large portion of the Province of Andalusia, in Spain; a country of which no maps exist that have any pretension to accuracy. The sketch and report, with which he has so obligingly supplied me, are descriptive of the road lately opened between Malaga and Granada; it is, however, only a part of the reconnoissance extending much further into the country.

not included within the limits of the sketch. Considering, therefore, the important consequences that hang upon the correctness of the information required, an officer should have ample time allowed him for the satisfactory discharge of so responsible a duty: for how often have the most brilliantly conceived operations failed, from the want of correct information on some apparently trifling point; and how frequently has the whole plan of a campaign miscarried through ignorance of the nature of some particular road: whereas, a General, provided with good plans, and detailed reports on the principal lines of communication through the country which is the seat of war, may act boldly and with vigour, instead of having to feel his way like a man in the dark.

In the form annexed, the columns for *distances* contain the measures in English miles; but it is recommended that all distances not ascertained from actual observation, such as lateral communications to towns, villages, &c., should be inserted in the body of the report in the common measures of the country, as received from guides and other persons.

It will be observed, that the plan in question commences at the bottom of the paper, being the manner in which it was drawn in the field: this is in every respect more convenient than beginning at the top. The columns for places, distances, &c., likewise proceed upwards; so that, by following the method here proposed, there need be no limitation to the extent of the sketch, and adjoining columns. It will also be seen, that the present arrangement admits of the leaves being turned over during a perusal of the report, without their concealing any portion of the plan, which will be found an advantage.

REPORT ON MALAGA, AND THE ROAD LEADING FROM THAT CITY TO GRANADA.

1. Malaga is the only port on the south coast of Spain, between Cadiz and Carthagena (a distance of one hundred leagues), whence roads suited to the purposes of an army penetrate into the interior of the country. The harbour of Malaga is formed by a stone pier, that juts upwards of half a mile into the sea, in a S.W. direction, and shelters it effectually to the east, the run of the coast protecting it on the opposite side. It is thus well sheltered from the prevailing winds that blow on this coast (due east and west); but is small, and so shallow as to admit only of a few frigates to ride in safety. The entrance is defended by some insignificant batteries, situated on the shore (à fleur d'eau) on its western side. At the mole-head is a lighthouse, with a revolving light.

The city itself may be considered as quite defenceless, for of the old Moorish wall that formerly enclosed it, but few vestiges remain; and the Gibralfaro, or citadel, built on the crest of a rocky promontory, overlooking both the city and harbour to the N.E., is a heap of ruins. The place covers a considerable extent of ground, and contains numerous large convents, hospitals, and other public buildings, well adapted for magazines and quarters for troops; as also barracks for several thousand men, and abundant stabling. The streets in general are narrow and crooked, but there are several fine open squares in different parts of the town. The houses are good, built chiefly of stone, and several stories in height.

The population of Malaga may be estimated at 60,000 souls, and is on the increase. The inhabitants occupy themselves principally in the preparation of wines and dried fruits, which are exported to an immense amount; but the city contains also numerous manufactories of silk, linen, and hats.

A mountain stream, distinguished by the name of the River Medina, or of Malaga, supplies the city with water. The valley which this rivulet irrigates is very fertile, but the vast plains bordering the Guadaljorce (which river falls into the sea about three miles to the west of Malaga), yield the rich crops of corn, maize, hemp, beans, &c., for which the city has ever been celebrated, and render it an admirable point on which to base military operations.

To the east of the city, the mountains terminate in rugged ramifications along the sea-shore: the coast, nevertheless, is not so rough but that a wheel road is practised along it to Velez Malaga, a distance of eighteen miles. The supplies furnished by that town, and its fruitful neighbourhood, are thus also readily brought into the market of Malaga.

The lofty range of Sierra, that rises at the back of the city, is a ramification of the great mountain-chain of Granada; which, stretching yet many miles further to the west, completes the serrated ridge that borders the Mediterranean shore from the confines of Murcia, to the Straits of Gibraltar.

At Malaga, two excellent roads present themselves to cross this difficult, and elsewhere almost impassable, range: the most westerly of these is directed on Antequera (twenty-eight miles), from which city two other wheel roads, but of a far inferior order, proceed to Seville and Cordoba; at which points respectively they unite with the great road of Cadiz to Madrid. But these roads, though important as opening excellent communications with the lower portion of the valley of the Guadalquivir, proceed too circuitously towards the pass of Despeñaperros—*the only passage across the Sierra Morena, from Andalusia into La Mancha* — to be adapted for military operations against Madrid; especially whilst the direct route from Malaga to the capital is open. This, which is the second of the good roads before alluded to, and the especial subject of this report, proceeds towards the pass of Despeñaperros, by Granada and Jaen; and whilst operating upon this road, a strong position offers itself for barring the approach to Malaga, by that from Antequera (should it be necessary), about five miles from the last-named city, at the pass of Cauche. (See sketch.)

From the asperity of the country between Malaga and Granada, the great road is unavoidably circuitous, being directed in the first instance on Loja, which town, though nearly north of Malaga, lies due east of Granada. A much more direct road offers itself between the two places, by way of Alhama, but it is a mere mule track, and moreover so completely cut off from the main road by impracticable mountains, as not even to be available to move a column of infantry upon, simultaneously with the other (with a view of forming a junction on the north side of the mountains), if in the presence of an enemy.

The main route traverses a very elevated range of country, but is so good, as to be throughout, and at all seasons, travelled by a diligence. It begins to mount a rude ramification of the distant mountain range, that divides the river Genil from the Mediterranean Sea, immediately on leaving Malaga, ascending by a gradual slope and innumerable windings, until it has attained the summit of the inferior ridge. This it accomplishes at the distance of four miles from the city, and is thenceforth carried along the crest of this narrow mountain spine, ascending gradually to a yet greater elevation, and looking down on cultivated valleys on either side; the steep acclivities of the ridge itself being planted with vines and olive trees.

2. At eight miles from Malaga, the summit of the ridge widens considerably, and a lofty conical mound here rising up, and protruding some way into the valley on the left, offers a strong position for checking any further advance along the road.

The road is conducted round the eastern base of this mound, the fall of which is so abrupt as to have rendered a bridge necessary to get round the head of a deep ravine that furrows the side of the range. The destruction of this bridge would occasion great delay under any circumstances, as from the steep and rugged nature of the ground, it would be a work of considerable time to practise a road in the side of the mountain.

The position, before alluded to, may be turned by moving round its right flank, but it would render a somewhat wide movement necessary, which, if successful to the fullest extent, would obtain no further result than that of rendering the position untenable, as the road of retreat for its defenders goes off from its left.

3. The road having passed round this hill again attains the summit of the ridge, and in three and a half miles reaches a lonely venta, or road-side public-house, the only habitation that has thus far presented itself. From hence the summit of the ridge becomes indented with rocky eminences, but the road is more level than heretofore, and keeps generally on the eastern side of the chain; whence it overlooks a wide extent of extremely intricate and broken country, which is chiefly planted with vines. At three miles there is another house, and two miles beyond this the road descends rather rapidly to El Colmenar. The elevated ground above this town affords a fine position for barring the road in either direction, but especially on the side of Malaga, where the approach would be exposed to an enfilading fire for the distance of a mile. A sketch of the ground on a large scale, and a detailed report on this position, is hereunto annexed.*

4. The road merely skirts El Colmenar, leaving it on the right hand. The town stands on a steep acclivity, and is encompassed on all sides by vineyards. There is a great want of wood in the neighbourhood, and the place is but indifferently supplied with water. The houses are good, and from the quantity of wine collected here the place contains many large storehouses. The population amounts to fifteen hundred souls.

5. There is a road from hence to Casabermeja, a large village situated in the valley on the left of the great route, and distant about four and a half miles from El Colmenar. From Casabermeja this cross road continues on to the pass of Cauche (before mentioned), where it falls in with the Chaussée from Malaga to Antequera. Artillery may be moved along this road without

* Not given here.

much difficulty, though it is not considered a wheel road; it thus serves as a useful connecting link between the two great routes.

The road continues to descend for upwards of a mile from El Colmenar, keeping along a low neck of land that connects the ridge the road had hitherto traversed with a far more elevated range of mountains that rises to the north. The ascent towards this lofty sierra now commences, and for two miles is very steep; the road, on attaining about one-third the height of the mountain, turns abruptly to the right, and keeps for four and a half miles under a perfect wall of precipitous rock, that offers a most formidable position. It is one however which, if turned on its left, would leave its defenders no retreat. A separate report on this position is annexed.*

6. About half a mile beyond where this ridge terminates to the east, is the solitary venta Dornejo, which, being usually made the resting-place of the muleteers and carriers between Malaga and Loja, is abundantly furnished with stabling.

7. Beyond this the mountains are tossed about in curious confusion, and the road, descending for a mile and a half, passes within musket-shot of the small village of Alfarnatejo, situated in a valley on the right.

8. A mile beyond this the road reaches the venta of Alfarnate, a small house, but abundantly furnished with stabling. Both this venta and the village of Alfarnatejo are well supplied with water, and the rough sides of the surrounding sierras now begin to be wooded.

9. A mile beyond the venta of Alfarnate, the village of that name is left three-quarters of a mile off on the right. This little place is watered by a fine stream, and has some cultivated ground in its vicinity.

In the three succeeding miles the road traverses a very difficult pass, which, though not so elevated as many parts of the ridge hitherto travelled, is in the principal mountain chain that runs through the country; the streams henceforward falling north-

* Not given here.

ward to the Genil. The pass is overhung by rocky precipices, and is thickly wooded with cork, oak, and ilex.

The numerous springs, abundant wood, and salubrity of this elevated district, render it an eligible site either for the formation of a camp of observation, or to move the troops to from Malaga during the autumn months; when that city and the places in its neighbourhood are frequently visited by yellow and typhus fevers, which occasion a great mortality amongst such of the inhabitants as have not the means of removing beyond their influence.

10. At the northern foot of the pass a small venta presents itself, situated on the bank of a copious stream, over which there is a good stone bridge.

The road from hence is conducted along the valley watered by this stream, and is practised in the side of a lofty mountain that overhangs it on the right. It proceeds in this way the whole distance to Loja (twelve miles), and is tolerably easy throughout, excepting for the space of a mile, about a league beyond the venta; the mountain there presses upon the stream and renders its bank very precipitous. The road is carefully made, however, being carried in easy zigzags along the rocky edge of the torrent.

11. At nine miles from the bridge and venta a road joins in on the left, from Antequera. This is the great road from Seville to Granada; and, excepting for the last three leagues, when it traverses a very mountainous country, is a tolerable carriage road. On this latter portion of it artillery could only be moved with great labour.

12. The town of Loja is situated under the northernmost point of the mountain, along the side of which the road is conducted, and which here falls very abruptly along the left bank of the river Genil. A rugged mountain falls equally precipitously along the opposite bank of the river; confining the stream, both above and below Loja, to a very narrow gorge.

The town occupies the widest part of this defile, but the houses are piled in steps, as it were, up the steep acclivity against which they rest, and the place thus completely closes the narrow passage. An old castle (in ruins) overlooks the town, and is itself looked into from the mountain at its back.

A good stone bridge, which, though narrow, is passable for every description of carriage, affords the means of crossing the Genil at all seasons, and communicates with a suburb on the right bank.

Traversing the bridge, a road proceeds to Alcala la Real, offering a much shorter road to reach Madrid than that by way of Granada; but for the first twenty miles this cross road is impracticable for artillery.

Loja has ever been celebrated as a military post of much importance, from the command it possesses of the only entrance on the western side of the fertile Vega of Granada; and although now undefended by walls, and receiving but slight protection from its dilapidated castle, it is, nevertheless, from its strong position, still a very defensible place. It contains four large convents, four hospitals, and a population of nine thousand souls. The country in its neighbourhood is extremely fruitful, producing corn, wine, oil, hemp, flax, and vegetables of all sorts. Wood and water are also plentiful.

The road to Granada takes an easterly direction on leaving Loja, keeping for yet two miles under the precipitous sierra that here overhangs the left bank of the Genil. It then reaches a small and highly-cultivated plain, watered by a fine stream, and a mile and a half further on arrives at the Venta del Pulgar, in the vicinity of which are several water-mills.

13. The venta is small, but has abundant accommodation for horses. Beyond it the road becomes rather heavy and is particularly lonely, there not being any village upon it, nor even near it, for many miles. The country is hilly, but very fertile, the sandy soil of the upper grounds producing corn; the alluvial deposit of the valley of the Genil, millet, Indian corn, hemp, &c., as well as pasturage, which henceforth is very abundant.

The Genil winds through a very level tract of country, and keeps generally at the distance of about a mile from the road;

it sometimes, however, approaches much nearer. The character of this stream is the same during the whole of its course through the Vega of Granada; its banks are low and earthy, its bottom muddy, rendering it dangerous to pass without a good knowledge of the different fords, changes in which are constantly effected by the winter torrents. The summer depth of water seldom exceeds three feet, and the current is sluggish; but in winter, and even during the autumnal rains, the stream is apt to rise very suddenly, and frequently overflows its banks laying the country under water to a considerable extent. These freshets at times rush down with such violence as to do much mischief, as well to the banks of the river as to the crops upon the plain.

14. At eight miles from the Venta del Pulgar, the village of Tajar is seen about a mile off the road on the left. It stands on the northern bank of the Genil, to cross which there is a ferry-boat, capable of passing over horses, or even light artillery when detached from the limbers.

15. At nine miles, the road fords the Cacin. This stream comes down from the Sierra of Alhama, and is at all seasons abundant. In winter it flows with great velocity, but is always passable: the bottom is hard and pebbly.

On the right bank of the stream stands the Venta de Cacin, a solitary house containing plenty of accommodation for horses.

16. Another ferry-boat, similar to the former, offers itself for crossing the Genil a mile beyond the venta, and about the same distance from the road. This ferry communicates with the village of Villa Nueva de Mesia, situated on the north bank of the river.

The country continues hilly all the way to Lachar, a distance of nine miles from the Cacin, and the road is still gravelly and heavy. The soil of the low grounds is particularly productive, but the crops are by no means fine on the uplands. Those grounds, however, are well suited to the vine and olive.

17. Lachar is a miserable village, but, being a post station, as well as a half-way resting place for carriers, &c., between

Loja and Granada, and being also principally inhabited by agriculturists, it contains abundant stabling. The vicinity of the Genil (which flows within two hundred yards of the place), and the quantity of grain produced in its neighbourhood, render Lachar an eligible cavalry station. Wood, however, is scarce.

Beyond Lachar the country on the right of the road becomes much more accessible, and may be considered as suited in every respect to the movements of an army; for though the roads traversing it, owing to the little use made of carts for agricultural purposes in this country, are narrow—in fact mere mule tracks—yet artillery, waggons, &c., may be moved across it without difficulty, and a good communication may now readily be opened with the mountain road from Malaga to Granada, by way of Alhama. Indeed, the village of Chimeneas, which is on one branch of that road, is but a mile and a half from Lachar, nearly south.

18. About a mile from Lachar a road strikes off to the left, passes the village of Cijuela, and crosses the Genil by a good ford at the hamlet of Fuente Vaquero, proceeding thence to the *Casa real del Soto de Roma,** where it branches off either to Piños de la Puente, on the road from Granada to Cordoba, or to Granada, keeping along the right bank of the Genil. Both these roads are passable for carriages of every description.

19. From Lachar to Santa Fé is eight miles. The miserable village of Chauchina is situated about a mile to the left of the road, two miles before reaching the last-named town. The road is nearly level throughout, and traverses the heart of the proverbially fertile Vega of Granada.

20. Santa Fé, though dignified with the title of city, is but a small walled village, containing two hundred houses, which, though mostly large, are in a ruinous condition.

The shape of the town is a perfect square. Its walls are four feet thick and twenty-five feet in height, and are flanked by projecting towers. Whilst, from the level nature of the country in

* On the Duke of Wellington's property.

the vicinity, Santa Fé thus offers a good *point d'appui* for infantry; yet its walls could make no prolonged resistance to artillery. It is badly supplied with water, and quite destitute of wood.

21. At a mile and a half from Santa Fé the road crosses a rivulet by a stone bridge,

22. And three miles beyond reaches the Genil, which it passes by a solid stone bridge of several arches. . .

The road now continues along the right bank of the river to Granada, a distance of three miles and a half, and is perfectly level throughout.

HEADS OF INSTRUCTION FOR RECONNOISANCE IN GENERAL.

The following memoranda will serve to point out the principal objects to which an officer employed in the important duty of reconnoitring, should direct his attention.

He must seek to acquire a good general knowledge of the country upon which he is to report, regarding its natural and political divisions, and principal features. He will then go into detail, dividing the subject into different heads, as:—

I.—*The peculiar nature of each district of Country, and its Productions.*

Particularizing what parts of it are mountainous or hilly, and what are level: whether the hills are steep, broken by rocky ground, rise by gradual and easy slopes; or, if the ground is undulated only in gentle swells. Whether the connexion of the high lands is obvious and continued, or if the heights appear detached from each other. In what directions the ridges run, and which are their steepest sides. The nature and extent of their valleys, and ravines — where they orignate, in what directions they run, whether difficult of access, or to be easily passed.

Whether the country is barren or cultivated, and what is the kind of cultivation — whether vines, or olives, or corn; and if the latter, what kinds of corn are grown, and in what parts it is most abundant. If a country of pasturage, whether it is grazed by cattle, by sheep, or by horses, and in what numbers; what parts of the country are open, and what are enclosed, and the description of the enclosures—whether small or extensive, formed by stone walls, ditches, hedges, or fences of any other kind. What parts of the country are wooded, and whether with grown timber or coppice wood; and with what species of trees; what the nature of the soil.

What is the nature of the country, in reference to the operations of troops; what parts of it are favourable for the acting of cavalry, and what for infantry only.

II.—*The Rivers and minor Streams, and Canals.*

The sources of rivers, and the direction of their course; whether they are rapid or otherwise; their breadth and depth, and what variations they are subject to, at different seasons of the year; the nature of their channels and of their banks; whether rocky, gravelly, sandy, or muddy; of easy or of difficult access: the bridges across them; whether of stone or of wood; their breadth and length; if accessible to artillery, and capable of bearing its weight. The nature of the fords, if always passable, or at certain times and seasons only; whether their situations change.* What rivers are navigable, and from and to what points, and by what description of vessels or boats. The ferries—their breadth, and the nature of the landing-place on each side; what description of boats are used at them; how many men, horses, or carriages, each boat is capable of conveying; how much time the passage requires, and in what manner it is performed. Canals — their course, breadth, and depth; the nature of the traffic carried on upon them; the number of boats usually to be found at different places, and the nature and dimensions of the boats; also, whether they are tracked by men or horses, or how otherwise navigated. Lakes and inlets of the sea — their situation, extent, and boundaries; what description of vessels can navigate them, &c., together with such of the above observations as are applicable to them. Marshes — their situation and extent; whether passable for troops in any part; and if they continue throughout the year, or exist only during the wet season.

* A ford should not exceed in depth, three feet for infantry, four feet for cavalry, and two feet and a half for artillery.

III.—*Population, Resources, Accommodation for Troops, &c.*

The size of towns and villages, and the number of their inhabitants; and whether well supplied with provisions or not. The number of houses, as also of churches, convents, or other public buildings; whether the houses are large and commodious, or small and mean; what number of troops could be accommodated in private houses, and what in public buildings, what stabling there is, or other cover for horses; if the town is walled or open, favourably situated for defence, or otherwise; if capable of being strengthened, and by what means. Similar observations in regard to detached convents, gentlemen's seats, farms, and other separate buildings. Plans or sketches of walled towns, defensible villages, or detached buildings, should always accompany the reports upon them. The number of carriages, horses, mules, or draught oxen, in possession of each town, village, or farm, should be stated; and what is the general means of conveyance made use of in the country: what mills exist in the town or vicinity, and whether turned by wind or water; the bake-houses, and quantity of bread they can produce in a given time; whether the place is unhealthy or not; if it be, whether it is in general unhealthy, or only so at particular seasons.

IV.—*Roads.*

Particular information must be obtained respecting the roads, in the description of which it is impossible to be too minute; the general nature of each road, as also all the variations which occur in it, from distance to distance, should be accurately described; whether the road has been regularly made, or appears to have been formed only by the use of the people of the country; whether it is fit for artillery or any description of wheel-carriage; for cavalry or for infantry only; over what description of soil it passes, whether rocky or gravelly, sandy, clayey, or earthy; and to what injuries it is liable in bad weather; whether it is easily repairable or not, what materials are requisite for that purpose, and whether they are to be found in the neighbourhood; whether any bad parts of the road, or the narrow and embarrassed streets of any of the towns or villages, can be avoided by going out of the road for a short distance; as, also, whether any great improvement could be made in the general direction of any part of the road, by adopting a new line altogether for a considerable distance; and what work is necessary in either of these cases. Particular attention should be paid to the ascents and descents upon the road; whether they are gradual and easy or abrupt, rugged or stony, having short turns or other difficulties; whether the road is wide enough in those parts which go along the side of a hill, and whether it is even, or is canted off the level so as to be unsafe for carriages. In those parts where the road passes between walls, or where it forms a hollow way between banks of earth, rocks, or other obstacles, its breadth ought to be measured; and it should be remarked also whether it can be widened, or the obstacles removed which confine it. The ferries, bridges, fords, &c., met with upon the road, should be particularly described; the possibility of obstructing or breaking up the road, so as to prevent its being used by the enemy, or of destroying the bridges or fords upon it, should be stated. The means of effecting these objects should be pointed out, as also the labour and time requisite for such a work. The distances of the places along the road should be given, both in the measures of the country and in English miles, averaged as accurately as possible. The time required to travel the different distances (at the ordinary walk of a man or of a horse) should also be stated. The places to the right and left, near the road, should be mentioned; their distances from the road, and at what points the communications to them strike off. Whether there are any railroads, and what facilities they offer for the rapid transport of troops, artillery, provisions, &c.

Care must be taken that the names of towns, villages, rivers, &c., are spelt in the same manner as by the natives of the country; and when the spelling and pronunciation differ very much, the name should also be written (in a parenthesis) as it is pronounced.

V.—*Camps and Positions.*

All strong passes, posts, or more extensive positions, which present themselves either upon the line of a road, or in any other situation; as also all places favourable for encamping or bivouacing troops, either with a view to position, or with reference merely to convenience upon a march, should be particularly described; their situation, extent, facility of access, nature of soil, supply of water at all seasons, quantity and kind of wood, and whether in sufficient abundance for hutting the troops, or only for furnishing fuel. A sketch of the ground upon a pretty large scale should always accompany these reports.*

In all reports, officers should state distinctly what parts of the information they contain rest upon their own personal examination of the objects in question, and what upon the authority of others; and, in the latter case, they should mention the source of their information, in order that a judgment may be formed of the degree of credit to which it is entitled.

* Sketches of positions should never be made upon a smaller scale than four inches to an English mile. More general sketches may be made upon a scale of two inches to a mile, and tracings of roads upon a scale of one inch to a mile.

The above heads of instruction are, with some slight additions, nearly a transcript of those issued by Sir George Murray, for the guidance of the officers of the Quarter-Master General's department, during the Peninsular War, and comprise almost every point to which reconnoissance should be directed; they, however, pre-suppose that officers to be employed in this most important duty are qualified to go into the necessary details implied under each head. Now, there is a vast deal to be learned before an officer can be considered as so prepared: it is not enough that he has eyes, he must further know how to use them.

Having now terminated a careful revision of my work, I send forth a new edition with confidence; no labour has been spared to render it a useful manual, by which any officer may qualify himself in a branch of military acquirement, which must, at one time or another, be of service to him in his profession: and, in order to show how much may be done with the aid of a very small portion of scientific knowledge, when zeal is combined with intelligence, I shall append a paper, which was most obligingly sent me by Major George Birch, an able officer of the Indian army, narrating the adventures and services of a native lad, who was employed by that gentleman, which will, I doubt not, interest my readers.

TO MAJOR JACKSON,

DEAR SIR,

In compliance with your wish, that I should give you a written account of what I narrated to you regarding a native of Hindostan, who acquired a very useful knowledge of surveying, &c., I will relate his history. His name was Savâaje Khan, a nephew of one of my head servants, from Rohilkund, in the Bengal Presidency. He was about thirteen years of age when I took him into my service, in 1804. I was then adjutant of a battalion of native infantry; and as I had some knowledge of surveying, I was directed whenever I marched with my corps to keep a route-book, and make a plan; noticing all towns, villages, forts, &c., on each side the way, with whatever observations or information I might think worthy of notice (this was in a newly-acquired country, and during the Mahratta war). This office was not very compatible with my duties of adjutant; and as we often marched during the night, I was then obliged, after the arrival of the corps on its ground, to proceed some distance on our next march, so as to have only half, perhaps, to do next morning after day-break. On these occasions, Savâaje Khan accompanied me on horseback; and he seemed so much interested in the occupation, that I showed him the use of the little circumferentor for taking angles; and when we were stationary for a day or two, he would ask me to lend it to him, that he might make sketches and plans of the surrounding country; which he soon effected, with such correctness and judgment, that he much assisted me; and thus he continued practising till 1807-8, when, my regiment being ordered to a distant place (Muttra), he asked leave to visit his family, and that he would rejoin me there; but he did not appear; and about four years elapsed without our having any tidings of him, so that we had given him up as lost; but to my surprise, when I was at Lodeanah on the river Sutlej, he stood before me with uplifted hands, after their manner of respect, and without uttering a word, till I recognised him. He then begged to relate his story: which was, that, on his way to meet me at Muttra, he fell in with a party of durwaishes going on a long pilgrimage to the holy shrines; that he had travelled with them across Hindostan and Persia to Mecca, and returned by the Caspian Sea: so holy a mission, as he expressed himself, and in such company, must plead his excuse for departure from duty to me, and he hoped that I would forgive him and restore him to my service; to which I most willingly agreed. I was then assistant to General Sir David Ochterlony, who was agent to the Governor-General, and commanding in the protected Sikh States. Sir David desired to have a conference with Savåaje Khan, to hear the history of his travels, &c., in which he was much interested. I soon afterwards informed Sir David of his talent for surveying, thinking that he might be employed with advantage in those countries where a European would not be admitted, and ascertain points upon which we had failed to gain satisfactory information. On stating the object to Savåaje Khan, he replied that he would willingly make the attempt, and would resume his pilgrim's attire as a disguise. He was to go down the bank of the Sutlej, until he reached Tatta, on its conflux with the Indus (or Attok, as it is called above that point), and to return by another route. I gave him his old favourite circumferentor, which nearly caused his destruction; for it was observed by one of a party where he stopped, when about ten days on his journey, and he was accused of being an impostor, and in the service of the English, and threatened with death; but he devised some excuse for possessing the instrument, which they could not guess the use of, and he was released under threats, and with some punishment. He then pursued his way and returned to us, after effecting his mission most satisfactorily.

Hostilities with the Goorkahs in the mountains were at that time in contemplation, and we had not any map of the country they possessed, as they had strictly prevented all Europeans from having access to it. One of the sons of the Goorkah governor, who commanded from the Ganges to the Sutlej (an extent of several hundred miles), was residing at Lodeanah, on Sir David's invitation, for medical aid; he was much with me, and consequently saw Savåaje Khan. Sir David wished to send Savåaje Khan into the mountains, to obtain some map and information of the anticipated scene of action, and he asked him if he would make the perilous attempt of traversing them, which he readily agreed to do: he immediately set off, and, in about six weeks, returned with so complete a book, that, with the base line I had of the frontier, I was able to execute the little map I send herewith for your inspection. Soon afterwards Sir David was ordered to take command of the division of the army operating against the Goorkahs, on the north-west of this map; and he sent a copy of it to Colonel Gillespie, who was to command a division for attack between the Ganges and Jumna, where, as you probably know, he fell gallantly heading a storming-party against the desperate resistance of the enemy at Kalunga. The operations of the campaign were commenced chiefly on Savåaje's map and information; and so correct was the former, that, a considerable time after the conquest of the whole country, on my showing it to the surveyor appointed by Government for that part of the country, he said it would be long before he could attempt to correct it, as it was done with extraordinary accuracy. Sir David told me that Savåaje Khan was most active and enterprising during his arduous campaign of about three months, and frequently gained very important information, and never deceived him. He was once taken prisoner; and the chief's son, who I have mentioned to have known him, and who was then fighting with his father against us, got his life spared on exacting his promise not to act against them again.

After that campaign, Sir David's being the only division out of five that had succeeded, he was called next year to the command of an army formed against the Goorkahs, opposite their capital (Katmandoo). They had so strongly fortified every pass, for some hundred miles along their formidable barrier of mountains, that Sir David perceived it must be a tedious and, from his experience, probably, desperate work to gain any of them; and the unhealthy season was so near, that he saw the necessity of some extraordinary enterprise, so he bribed a smuggler to tell him of his means of evading the passes; and the smuggler, as he expressed himself, said he could show him where a wild goat or a man like himself could climb, but nothing else; and if rain fell it would be quite impracticable for them to do so, from the torrents of water. This was enough for Sir David's ardent spirit: he immediately ordered a strong division of the army to march that night with guns upon elephants, and their carriages to be taken to pieces and conveyed with them; and, with the smuggler as a guide, they cut through the jungle and got up through the most wild and rugged crags and cliffs, until at day-break they found themselves in the rear of a succession of batteries and stockades, which they at once carried by assault: and that day so appalled the enemy, that they yielded everything that was required, and so ended the war. I send you Sir David's note to me on the occasion, and also sketch by an officer of part of the pass they had to ascend.

Sir David took Savâaje Khan with him, and wrote to me that he had evinced his usual zeal and intelligence; and that, as he thought I was not likely to require his services, in my civil capacity as his successor over the Sikh States, he knew I would be glad of his serving so meritorious and worthy a man; and he had got him established in the Surveyor-General's or Quarter-Master-General's department, on his representation of his great services and abilities.

I fear that I have given you too lengthy a detail, but I beg that you will curtail or use any part of it in the way you proposed to honour it, or as it may seem best to you; and I beg to add, as encouragement to any young man who may be about to enter the Indian army (in which I served upwards of twenty-two years in various capacities), that, in the fine field it presents for bringing every kind of qualification into action, not only the military sciences, but *every species of acquirement* is sure to meet with attention, and in due time be rewarded by employment, either in or out of the possessor's appointed station, and lead him to honour and emolument. Young men are generally not aware, or sufficiently thoughtful, of the value of attainments and conduct towards gaining distinction and reward. They often suppose them to be less the recompense of merit than the result of interest; but I can say, to the credit of our Indian governors and governments, that I have generally seen the former to prevail: indeed, the late Lord Hastings publicly announced, that he would employ abilities and character wherever he found them, without attention to any other supposed claims; and I will here mention an anecdote of that nobleman's extraordinary attention to that principle. A general officer, more than eight hundred miles from Calcutta, showed me a letter in the Governor-General's own hand-writing, containing a long list of the officers under the General's command; with notes opposite each name as to their qualifications for various appointments, although those corps had never been near him. The General justly observed, "How a sight of this list would electrify these men: how little aware are they of being thus known!"

Believe me, dear Sir,

Yours faithfully,

G. BIRCH,

Major, Bengal Infantry, retired.

CLARE, near Farnham, Surrey,
10*th Dec.*, 1840.

COMPARISON
OF
ENGLISH AND FRENCH
MEASURES AND WEIGHTS.

		Mètres.
The English mile of 1760 yards	=	1609·31
The imperial yard	=	0·9143
The foot	=	0·3047
The pint, or 1-8th of a gallon = in *litres*		0·5679
The pound troy = in *kilogrammes*		0·3730

EUROPEAN MEASURES.

GERMANY.

		Mètres.
The geographical mile, of 15 to a degree	=	7419·34

AUSTRIA.

The mile, of 10,000 paces, or 4000 toises of Vienna	=	7586·40
The Vienna foot	=	0·316

PRUSSIA.

The mile, according to Hoyer	=	7747·42

SAXONY.

The mile	=	9271·00
The Dresden foot	=	0·283

BAVARIA.

The mile, according to Hoyer	=	7876·06

HANOVER.

The mile, according to Hoyer	=	10587·93
The foot	=	0·292

SWEDEN.

	Mètres.
The mile, of 18,000 Swedish alner .... =	10687·00
The Swedish foot .... =	0·296

BRABANT AND POLAND.

The mile, of 20 to a degree .... =	5564·50

RUSSIA.

The verst, of 500 toises, or 1500 acchinis .... =	1066·77
The foot .... =	0·355

SWITZERLAND.

The mile .... =	7386·00
The Basle and Zurich foot .... =	0·300

SPAIN.

The league (new), or 8000 vares of 16·6 to a degree =	6689·00
The league (legal), of 500 vares of Lopez, of 26·5 to a degree .... =	4173·00
The Spanish foot .... =	0·278

PORTUGAL.

The league, of 18 to a degree .... =	6173·00

Palmer and Clayton, 10, Crane Court, Fleet Street.

APPENDIX.

I.—PORTABLE TRIGONOMETRY, WITHOUT LOGARITHMS.

[The following useful application of Trigonometry, by means of the natural sines, tangents, &c., is taken from an early number of that valuable periodical, the Mechanics' Magazine; and will be found particularly suited to the purposes of the Military Surveyor.]

In all the more elaborate and refined operations of trigonometry, as well as their applications to navigation, astronomy, and geodesic surveying, it is not only desirable, but necessary, to employ some of the larger logarithmic tables, as those of Hutton, Babbage, Callet, Taylor, &c., both to save time and to ensure the requisite accuracy in the results. But, in the more ordinary operations, as in those of common surveying, ascertaining inaccessible heights and distances, reconnoitring, &c., where it is not very usual to measure a distance nearer than within about its thousandth part, or to ascertain an angle nearer than within two or three, or in very rare cases within one minute, it is quite a useless labour to aim at greater accuracy in a numerical result. Why, for example, should I compute the length of a line to the fourth or fifth place of decimals, when it must depend upon another line, whose accuracy I cannot ensure beyond the unit's place? Or, why compute an angle to seconds, when the instrument employed does not ensure the angles in the data beyond the nearest minute?

Hence several mathematicians, as Euler, Legendre, Hutton, Bonnycastle, &c., have investigated approximating series and other rules, for solving the cases of trigonometry without tables; yet, however ingenious their researches may have been, they have not led to any results of practical value, but simply furnish so many proofs, how easy it is for scientific men, in their investigations, to miss the point of real utility.

It is truly extraordinary, that amid all this search for expedients, the obvious method which I now beg to recommend and exemplify, has never been thought of. In the table herewith given, and which, set up with a bold, clear type, occupies only an octavo page, I have brought together the *natural* sines, tangents, and secants, to every degree in the quadrant; and have no doubt that this table, though only carried to five places of decimals, will be found sufficiently extensive and sufficiently correct for the various practical purposes to which I have adverted. And thus, the surveyor, the architect, the civil or military engineer, furnished with this table, in one page, a 100-feet tape, a pocket sextant, or a portable theodolite, may take every angle and perform every computation that can occur in the most useful cases.

The requisite proportions must, it is true, be worked by multiplication and division, instead of by logarithms. Yet this by no means involves such a disadvantage as might seem at first sight. For when the measured lines are expressed by three, or at most by four figures (and to give more only presents an appearance of accuracy which does not exist), the multiplications and divisions are performed nearly as quick, and in some cases quicker (as will be seen) than by logarithms. Besides which, the operations may often be shortened, by resolving numbers into their component factors, and by other contractions well known to practical men. Nay, if this were not the case, the circumstance would not present any serious objection: for, when a computation is not to be performed once in a month, it does not greatly signify whether you complete it in ten minutes or in twenty.

Then, as to accuracy: even in cases where the computer will have to take proportional parts for the minutes of a degree, the result may usually, if not always, be relied upon to within about a minute: and, recollecting that in the out-of-door operations he has it commonly at his option to fix his instrument at angles measured by *degrees* precisely, by simply advancing or receding for vertical angles, or moving to the right or left for horizontal ones, or a little varying the position of a station-staff; thus at once ensuring a simplified calculation and a more accurate result. The accuracy will also be augmented by some of the expedients which I shall explain as I go along.

A TABLE OF NATURAL SINES, COSINES, TANGENTS, COTANGENTS, SECANTS, AND COSECANTS,

TO EVERY DEGREE OF THE QUADRANT.

Deg.	Sines.	Cosines.	Tangents.	Cotangents.	Secants.	Cosecants.	
0	00000	1·00000	00000	Infinite.	1·00000	Infinite.	90
1	01745	99985	01745	57·2900	1·00015	57·2987	89
2	03490	99939	03492	28·6363	1·00061	28·6537	88
3	05234	99863	05241	19·0811	1·00137	19·1073	87
4	06976	99756	06993	14·3007	1·00244	14·3356	86
5	08716	99619	08749	11·4301	1·00382	11·4737	85
6	10453	99452	10510	9·51236	1·00551	9·56677	84
7	12187	99255	12278	8·14435	1·00751	8·20551	83
8	13917	99027	14054	7·11537	1·00983	7·18530	82
9	15643	98769	15838	6·31375	1·01246	6·39245	81
10	17365	98481	17633	5·67128	1·01543	5·75877	80
11	19081	98163	19438	5·14455	1·01872	5·24084	79
12	20791	97815	21256	4·70463	1·02234	4·80973	78
13	22495	97437	23087	4·33148	1·02630	4·44541	77
14	24192	97030	24933	4·01078	1·03061	4·13356	76
15	25882	96593	26795	3·73205	1·03528	3·86370	75
16	27564	96126	28675	3·48741	1·04030	3·62796	74
17	29237	95630	30573	3·27085	1·04569	3·42030	73
18	30902	95106	32492	3·07768	1·05146	3·23607	72
19	32557	94552	34433	2·90421	1·05762	3·07155	71
20	34202	93969	36397	2·74748	1·06418	2·92380	70
21	35837	93358	38386	2·60509	1·07114	2·79043	69
22	37461	92718	40403	2·47509	1·07853	2·66947	68
23	39073	92050	42447	2·35585	1·08636	2·55930	67
24	40674	91355	44523	2·24604	1·09464	2·45859	66
25	42262	90631	46631	2·14451	1·10338	2·36620	65
26	43837	89879	48773	2·05030	1·11260	2·28117	64
27	45399	89101	50952	1·96261	1·12233	2·20269	63
28	46947	88295	53171	1·88073	1·13257	2·13005	62
29	48481	87462	55431	1·80405	1·14335	2·06266	61
30	50000	86603	57735	1·73205	1·15470	2·00000	60
31	51504	85717	60086	1·66428	1·16663	1·94160	59
32	52992	84805	62487	1·60033	1·17918	1·88708	58
33	54464	83867	64941	1·53986	1·19236	1·83608	57
34	55919	82904	67451	1·48256	1·20622	1·78829	56
35	57358	81915	70021	1·42815	1·22077	1·74345	55
36	58778	80902	72654	1·37638	1·23607	1·70130	54
37	60181	79863	75355	1·32704	1·25214	1·66164	53
38	61566	78801	78129	1·27994	1·26902	1·62427	52
39	62932	77715	80978	1·23490	1·28676	1·58902	51
40	64279	76604	83910	1·19175	1·30541	1·55572	50
41	65606	75471	86929	1·15037	1·32501	1·52425	49
42	66913	74314	90040	1·11061	1·34563	1·49448	48
43	68200	73135	93251	1·07237	1·36733	1·46628	47
44	69466	71934	96569	1·03553	1·39016	1·43956	46
45	70711	70711	1·00000	1·00000	1·41421	1·41421	45
	Cosines.	Sines.	Cotangents.	Tangents.	Cosecants.	Secants.	Deg.

THE TABLE.

The preceding Table is so arranged, that for angles not exceeding 45 degrees, the sine, cosine, tangent, cotangent, &c., for any number of degrees, will be found *opposite* the proposed number in the *left-hand* column, and in the column under the appropriate word. When the number of degrees in the arc or angle exceeds 45 degrees, that number must be found in the *right-hand* column, and *opposite* to it in the column indicated by the appropriate word at the *bottom* of the table. Thus, the sine and cosine of 36 degrees are ·58778 and ·80902 respectively, the tangent and cotangent of 62 degrees are 1·88073 and ·53171 respectively; the radius of the table being unity, or 1.

The taking proportional parts for minutes, can only be done correctly (that is, independently of the rules of interpolation) in those parts of the table where the differences between the successive sines, tangents, &c., run pretty uniformly. In that case, the mode to be employed will be evident from a single example. Suppose we want the natural sine of 20° 16′. The sine of 21 degrees is 35837, that of 20 degrees is 34202; their difference is 1635. This divided by 60 gives 27·25, for the proportional part due to 1 minute, and that again multiplied by 16, gives 436, for the proportional part for 16 minutes. Hence the sum of 34202 and 436, or 34638 is very nearly the sine of 20° 16′. And so of others. But observe that the operation may often be contracted, by recollecting that 10 minutes are 1-6th, 15 minutes are 1-4th, 40 minutes are 2-3rds of a degree, and so on. Observe, also, that for cosines, cotangents, and cosecants, the results of the operations for proportional parts are to be *deducted* from the value of the required trigonometrical quantity in the preceding degree.

USEFUL THEOREMS.

1. cosine $= \sqrt{(1-\sin^2.)}$
2. sine $\div$ cosine $=$ tangent.
3. cosine $\div$ sine $=$ cotangent.
4. $\sin.^2 + \cos.^2 = \text{rad}^2$.
5. $\text{rad}.^2 + \tan.^2 = \text{secant}^2$.
6. $1 \div$ tan. $=$ cotangent.
7. $1 \div$ cotan. $=$ tangent.
8. $1 \div$ sine $=$ cosecant.
9. $1 \div$ cosine $=$ secant.
10. $1 \div$ cosecant $=$ sine.
11. $1 \div$ secant $=$ cosine.
12. rad. $-$ cosine $=$ versin.

Thus, we may often, instead of dividing by a sine, multiply by the cosecant, instead of dividing by a tangent multiply by the cotangent of the same arc; and so of others.

RIGHT-ANGLED TRIANGLES.

1. $(\text{hypoth.})^2 = \text{base}^2 + \text{perp.}^2$
2. $\text{base}^2 = (\text{hypoth.} + \text{perp.}) \times (\text{hypoth.} - \text{perp.})$
3. $\text{perp.}^2 = (\text{hypoth.} + \text{base}) \times (\text{hypoth.} - \text{base.})$
4. perp. $=$ base $\times$ tan. angle at base.
5. hyp. $=$ base $\times$ sec. angle at base.
6. perp. $\div$ base $=$ tan. angle at base.
7. base $\div$ perp. $=$ tan. angle at vertex.
8. hypoth. $\div$ base $=$ sec. angle at base.
9. hypoth. $\div$ perp. $=$ sec. angle at vertex.
10. base $\div$ hypoth. $=$ cosine angle at base.
11. perp. $\div$ hypoth. $=$ sine angle at base.

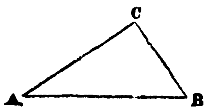
PLANE TRIANGLES, GENERALLY.

Case 1.—When a side and its opposite angle are two of the given parts.

Then, as any one side is to the sine of its opposite angle, so is any other side to the sine of its opposite angle.

The first term of the proportion must be the sine of a given angle, whose opposite side is also given, when a side is required. If an angle is required, begin the proportion with a given side opposite a given angle.

Remember, that the three angles of every plane triangle, when added together, make precisely 180 degrees.



Case 2.—When two sides, and the angle included between them are given, to find the third side: as suppose A C, A B, and and the angle A are given. Then $CB = \sqrt{(AC^2 + AB^2 - 2AC \cdot AB \cdot \cos. A)}$. After CB is thus found, the angles C and B, if required, may be found by the rule in the 1st Case.

Case 3.—When the three sides are given, to find the angles. Find one angle, as suppose A, by the theorem,

$$\cos. A = (AC^2 + AB^2 - BC^2) \div 2AC \cdot AB;$$

then another angle by the rule to the 1st Case, and the third angle by taking the sum of the other two from 180 degrees.

Sometimes it will be better to determine one of the unknown angles, by means of a theorem for its *half.* Thus, if half the sum of the three sides be denoted by S, we shall have

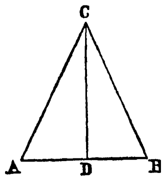
$$\sin. \tfrac{1}{2} A = \sqrt{\frac{(S-AB) \cdot (S-AC)}{AB \cdot AC}}$$

I have thus brought together the most useful rules in plane trigonometry, that your practical readers may have all the requisite information before them in one place; and shall now conclude with a few examples in

HEIGHTS AND DISTANCES.

And here, for the sake of facilitating the comparison with a well-known book, I shall select from the second volume of "Hutton's Course of Mathematics."

Example 1.—Two stations, A and B, are assumed in a horizontal plane, and it is required to find their distance from an inaccessible object, C, in the same horizontal plane.



A B is measured = 200, the angle A is found to be 68° 2′, and B = 73° 15′. Required A C and B C. (Hutton, p. 24.)

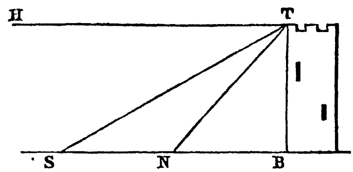
Here 180° − (A + B) = 38° 43′ = C. Then, proportioning as before explained for the minutes, we have sine C = sin. 38° 43′ = ·62545; sin. A = sin. 68° 2′ = ·92739; sin. B = sin. 73° 15′ = ·95755. Then, working with these numbers and A B = 200, we have, from Case 1,

sin. C : A B :: sin. B : A C = 306·19; Dr. H's answer is 306·19
sin. C : A B :: sin. A : B C = 296·55; Do. 296·54

I omit the work at large to save room.

Note.—In a great majority of cases, an inaccessible distance may be obtained by a still simpler process. Thus, choose the first station at D, so as to make a right angle, C D A, with the line A B: then set the sextant, or other instrument for measuring angles, to any suitable angle expressed in degrees, as 70°, 60°, 54°, 52°, 45°, &c., and retire from D along D A, until the angle C A D accords with that to which you have set the instrument. Then, D C = D A × tan. A, and A C = D A × sec. A.

Example 2.—From the top of a tower, by the sea side, of 143 feet high, the angle of depression of a ship's bottom was observed to be 35°: what was the ship's distance from the bottom of the wall? (Hutton, p. 25.)



In the annexed figure, where T H, B S, are horizontal, T B vertical, the latter is given $= 143$; also angle $HTS = 35°$, whence $STB = 90° - 35° = 55°$. But B S is evidently the tangent of the angle S T B to the radius T B. Hence, $BS = TB \times \tan. STB = 143 \times 1{\cdot}42815 = 204{\cdot}22$, agreeing with Dr. H.'s answer.

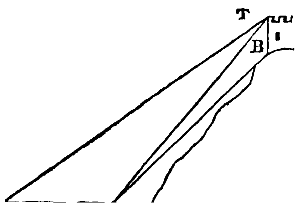
Example 3. —Wanting to know the distance between two inaccessible objects, N S (preceding figure), on a horizontal plane, the angles $STB = 64\frac{1}{2}°$, $NTB = 33°$, were taken from the top of a tower whose height, B T, was known to be 120 feet. Required N S. (Hutton, p. 24.)

Here S N is evidently equal to the difference of the tangents of S T B and N T B, to the radius T B.

Now, the differences of the tangents above 60° increasing rapidly, the common use of the proportional parts would give the tangent of 64° 30′ too great. I, therefore, find the cotangent of $64° \, 30' = {\cdot}477$ nearly, and from the principle of theor. 7, find $1 \div {\cdot}477 = 2{\cdot}0964 = \tan. 64\frac{1}{2}°$. The tan. of $33° = {\cdot}64941$. Therefore, $(2{\cdot}0964 - {\cdot}64941)\, 120 = 1{\cdot}44699 \times 120 = 173{\cdot}6388 = SN$. Dr. H.'s answer is 173·657, differing by about the 10,000dth part.

Example 4.—Wanting to know the height of an inaccessible tower, I took two angles in the same vertical plane, viz. $N = 58°$, $S = 32°$ (preceding figure), and measured the horizontal distance, N S, between the stations $= 300$. Required the height, B T, of the tower, and my distance, N B, from it at the nearest station. (Hutton, p. 25.)

In this case, by simply reversing the process in the last example, N S, divided by the difference of the tangents of S T B and N T B, or the difference of the cotangents of S and N will give B T; and $BT \times \text{cot. } N = BN$. But cot. $32° = 1{\cdot}60033$, and cot. $58° = {\cdot}62487$, their diff. $= {\cdot}97546$. Hence, $300 \div {\cdot}97546 = 307{\cdot}55 = BT$; and $307{\cdot}55 \times {\cdot}62487 = 192{\cdot}17 = BN$. Dr. H.'s answers are 307·53 and 192·15; and the logarithmic method requires 12 lines, besides turning to several different pages of the tables.



Example 5.—In order to find the height of a tower T B, that stood on the top of a hill, at two stations N, M, whose horizontal distance measured 200 feet, I took the vertical angles, $PNB = 40°$, $PNT = 51°$, and $PMT = 33° \; 4'$, all in the same vertical plane. Required T B. (Hutton, p. 26.)

This example may be worked either by means of the tangents and cotangents, or by the sines; let us here employ the latter. Sin. $MTN = \text{sin. } (TNP - TMP) = \text{sin. } 17° \; 15' = {\cdot}29654$; sin. $TMN = \text{sin. } 33° \; 45' = {\cdot}55556$, found by the proportional parts, as before described; sin. $B = \text{sin. } 50° = \text{sin. } 130° = {\cdot}76604$; sin. $BNT = \text{sin. } (51° - 40°) = \text{sin. } 11° = {\cdot}19081$. With these numbers and $MN = 200$, work the following proportions :—

sin. $TMN : MN :: \text{sin. } TMN : TN = 374{\cdot}695$

and sin. $B : TN :: \text{sin. } BNT : BT = 93{\cdot}3313$. Dr. H.'s answer is 93·33148.

Example 6.—Wanting to know the distance between two headlands, I measured from each of them to a certain point inland, and found the two distances to be 735 and 840 yards, and the horizontal angle between those two lines 55° 40′. Required the distance. (Hutton, p. 27.)

Here, referring to the figure in Case 2, Plane Triangles, there are given $AC = 735$, $AB = 840$, and angle $A = 55° 40'$. Observe also that $735 = 105 \times 7$, and $840 = 105 \times 8$; and that, therefore, we may proceed as though AC were 7 and AB 8; multiplying the final result by 105.

The cosine of $55° 40' = \cos. 55° - \frac{2}{3}$ diff. cosines of 55° and $56° = {\cdot}564$ very nearly. Hence, taking the expression in Case 2, we have,

$$
\begin{aligned}
CB &= 105\sqrt{(7^2+8^2-2{\cdot}7{\cdot}8 \times {\cdot}564)} \\
&= 105\sqrt{(49+64-63{\cdot}168)} \\
&= 105\sqrt{49{\cdot}832} \\
&= 105 \times 7{\cdot}05917 \\
&= 741{\cdot}21 \text{ yards. Dr. H.'s answer is } 741{\cdot}2.
\end{aligned}
$$

The above will suffice to exemplify the manner of operation, as well as to prove the accuracy of the method; which, as will thus appear, is greater than I have hypothetically assigned it.

In what is here done, I shall not, I trust, be supposed attempting to supersede the use of the excellent tables referred to at the commencement of this paper, or the correct theoretical processes which they so greatly facilitate. I am solely anxious to explode all the crude and usually erroneous tentative methods adopted by those who are not conversant with the nature and use of logarithms, by showing that, without the aid of those artificial numbers, a table of natural sines, tangents, &c., comprehended in a single page, will enable a computer, by simple operations in decimal arithmetic, to solve problems in trigonometry, and inaccessible heights and distances, with all the accuracy that can be desired by practical men.

The same table will be found of equal utility in the mechanical inquiries which relate to the parallelogram of forces, oblique pressures, motions on inclined planes, the usual practice of gunnery, &c. But fearing that I shall have already greatly encroached upon your pages, I can only hint at these applications now.

I am not, however, without hopes, that what is here done will stimulate some individual of more leisure than myself to turn his attention to the abbreviation of a table of *logarithms*. I have seen such a table in a single sheet; and M. Wronski proposed to reduce it to a single *page*. If, however, a correct table to five places of decimals could be presented in about *four pages*, then two more pages might contain such a table as the preceding, and an analagous table of logarithmic sines, tangents, &c. A single sheet might thus be made to exhibit all the tables, precepts, and rules, necessary in the common practice of trigonometry, and in the computation of annuities and reversions. Much shall I rejoice if some of your correspondents enable you to present to the public so valuable a gift.

P. M. W.

II.—TO DETERMINE ALTITUDES

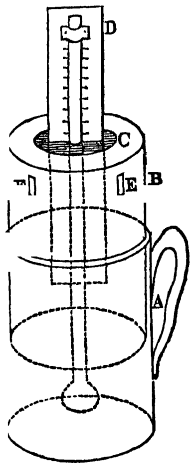
BY THE DIFFERENT TEMPERATURES OF BOILING WATER.

If water be placed in a suitable vessel on a common fire, or over the flame of a lamp, it is gradually heated to a certain degree; and then small bubbles of aëriform matter (steam) are seen forming at the bottom of the vessel, and successively rising to the surface, where they disappear by mixing with the atmosphere; and the operation being continued, the quantity of water diminishes with every bubble, until the whole disappears in the form of air.

Under common circumstances, this change in water takes place when it has attained the heat of 212° of the thermometer (Fahrenheit's). But a less degree of heat produces the same effect if the pressure of the atmosphere be lessened or removed; and a greater degree is required when the atmospheric pressure is increased. On the summit of Mont Blanc, water boils at 180°, owing to its being relieved from the pressure of a column of air equal to the height of the mountain; and at all intermediate heights in descending to the level of the sea, there is a corresponding increase of the boiling temperature. Hence is derived a valuable method of ascertaining the heights of places, by simply observing the heat at which water boils.

A paper has recently been published, by that scientific officer, Lieut. Colonel W. H. Sykes, of the Indian Army, on the method of determining heights by this means; and Mr. Prinsep having computed the necessary tables, the operation is thereby rendered exceedingly simple. The results obtained by using these tables, give a rather less elevation than what we arrive at by careful barometrical observations. It is not, however, to be supposed that either the thermometer when immersed in boiling water, to the barometer when used with the table and formulæ, as given at page 272, and following ones, of this book, can ever furnish so exact a measurement as we obtain by levelling, or trigonometrically; still, as both methods afford a close approximation, they are of great value: and with reference to that by boiling water, the necessary apparatus is very simple, and not liable to injury like the barometer, besides being more portable and easily replaced, should an accident occur.

The accompanying sketch and explanation, taken from Colonel Sykes's pamphlet, show the whole apparatus required:—



A, a common tin pot, 9 inches high, by 2 in the diameter.

B, a sliding tube of tin, moving up and down in the pot; the head of the tube is closed, but has a slit in it, C, to admit of the thermometer passing through a collar of cork, which shuts up the slit where the thermometer is placed.

D, thermometer, with so much of the scale left out as may be desirable.

E, holes for the escape of steam.

The pot is filled four or five inches with *pure* water; the thermometer fitted into the aperture in the lid of the sliding tube, by means of a collar of cork; and the tin sliding tube pushed up or down to admit of the bulb of the thermometer being about two inches from the bottom of the pot.

Before using a thermometer for this purpose, it is necessary to ascertain if the boiling point is correctly marked for the level of the sea by a number of careful observations, and the difference, if any, must be noted as an *index error*. It is always desirable to have two or more thermometers which have been thus tested, and in all observations the temperature of the air at the time should be noted.

A few minutes will suffice for the whole operation; and where *very great accuracy* is not required, this method is certainly preferable to the barometer for determining altitudes, on account

When the boiling point at the upper station alone is observed, and for the lower the level of the sea, or the register of a distinct barometer is taken, then the barometric reading had better be converted into feet, by the usual method of subtracting its logarithm from 1·47712 (log. of 30 inches) and multiplying by ·0006, as the differences in the column of "*barometer*" vary more rapidly than those in the "*feet*" column.

		feet.
Example:—Boiling point at upper station....	$185° =$	14548
Barometer at Calcutta (at 32°) 29in. 75		
Logar. diff. $= 1·47712 - 1·47349 = 00363 \times 0006 =$		218
Approximate height......		14330
Temperature, upper station, 76° / Ditto lower, 84	$\}$ 80 = multiplier	1·100
Correct altitude..........		15763

Assuming 30·00 inches as the average height of the barometer at the level of the sea (which is however too much), the altitude of the upper station is at once obtained by inspection of Table I., correcting for temperature of the stratum of air traversed by Table II.

THE END.