May 2, 1872.

The EARL OF ROSSE, D.C.L., Vice-President, in the Chair.

In conformity with the Statutes, the names of the Candidates recommended for election into the Society were read from the Chair as follows:—

Prof. William Grylls Adams, M.A.
Andrew Leith Adams, M.B.
Frederick Le Gros Clark, F.R.C.S.
Prof. John Cleland, M.D.
Prof. Michael Foster, M.D.
Prof. Wilson Fox, M.D.
Arthur Gamgee, M.D.
Rev. Thomas Hincks, B.A.
Prof. William Stanley Jevons, M.A.
Prof. George Johnson, M.D.
Prof. Thomas Rupert Jones.
Major Thomas George Montgomerie, R.E.
Edward Latham Ormerod, M.D.
Edward John Routh, M.A.
William James Russell, Ph.D.

The following communications were read:—

I. "On a new Great Theodolite to be used on the Great Trigonometrical Survey of India, with a short Note on the performance of a Zenith-Sector employed on the same work." By Lieut.-Colonel A. Strange, F.R.S., Inspector of Scientific Instruments, India Department. Received April 25, 1872.

On the 28th of February, 1867, I had the honour of submitting to the inspection of the Royal Society a Transit-Instrument and a Zenith-Sector made for the Great Trigonometrical Survey of India, to be used respectively for the determination of longitude and latitude on that work. These were one instalment of the following list of geodesical and astronomical instruments which the Secretary of State for India deputed me to design and superintend under construction:—

One Great Theodolite, with a 3-feet Horizontal Circle. By Messrs. Troughton and Simms.

Two Zenith-Sectors. By Messrs. Troughton and Simms.

Two 5-feet Transit-Instruments. By Messrs. T. Cooke and Sons, York.

Two smaller Transit-Instruments (*German form*). By Messrs. T. Cooke and Sons, York.

Two 12-inch Vertical Circles (*German form*). By Messrs. Repsold, Hamburg.

Two Galvanic Chronographs for registering Transit-Observations. By MM. Secretan and Hardy, Paris.

Three Astronomical Clocks. By Mr. Charles Frodsham.

The Zenith-Sector was, shortly after its exhibition to the Society, forwarded to its destination, as have been more recently the other Zenith-Sector, one of the 5-feet Transit-Instruments, the two 12-inch Vertical Circles, the two Galvanic Chronographs, and the three Astronomical Clocks. Of these, the first forwarded Zenith-Sector alone has been used in actual field-operations. It has been employed during two seasons in determining latitudes in Southern India, by Capt. J. Herschel, R.E., F.R.S., of the Great Trigonometrical Survey. One of my main objects in designing the instrument, which is entirely unlike any of its class, was to qualify it for more rapid observing than had hitherto been possible. In this respect it has been successful. Capt. Herschel reports that he can observe with it a series of stars differing only five minutes of time in Right Ascension. Each star is observed twice in reversed positions of the telescope at the same culmination, in the manner prescribed by the Astronomer Royal for the Zenith-Sector designed by him for the British Ordnance Survey. Each of these two reversed observations involves two settings of the telescope in altitude, four microscoped, two level, and one micrometer reading. To admit of all these operations being performed within five minutes of time with the deliberation requisite for observations aiming at fractions of a second, demands not only convenience of instrumental construction, but the greatest system and efficiency in the observatory arrangements, and a very high order of skill on the part of the observer.

In the latest Report on the Survey, that for 1870-71 by Major Montgomerie, R.E., Officiating Superintendent, that officer states that "Captain Herschel's further experience with the Zenith-Sector has on the whole confirmed his first impressions as to its excellence." Captain Herschel reports on an anomaly in the level readings, amounting, as I understand through private sources, to about $0''\cdot 3$, the cause of which he has not yet been able to detect. It may possibly, as he suggests, be partly due to the rigidity of the instrument as a whole not being absolute. I am myself inclined to suspect that imperfections in the levels themselves may in some measure contribute to the observed discrepancies. The levels have been reported, and are known to me, as deficient both in uniformity of run and in sensibility; they are certainly not on a par with the graduation, which is superb, or with the optical power of the telescope and microscopes. The accuracy of the instrument is thus limited by that of the levels, which are its weakest member. I may here state incidentally that I have not been able to procure levels in England which come up to the standard now required, and I must therefore have recourse to foreign makers, who have paid more attention to these adjuncts than, as it seems, it is worth the while of our English artists to do.

Comparing the facility of working the Zenith-Sector and the former Astronomical Circles, Captain Herschel says:—"The Sectors are competent to turn out at least double the amount of work *of the same order*," adding, "at this rate two or three years' work would equal in amount the

whole results up to the date of the arrival of the Sectors; and ten years (a comparatively short period for which to arrange a system of observation on a matter of this magnitude) will see us in a position to look back on the arrival of the Sectors as on the commencement of a new era."

I now pass to the Great Theodolite, which I do myself the honour this evening to expose to the scrutiny of the Royal Society. A brief history of the design of this instrument may here with propriety be recorded.

There are at present at the disposal of the India Survey Department two instruments of the same order as the one under consideration, namely, Theodolites having Horizontal Circles 3 feet in diameter, the largest dimension hitherto employed,—hence the term Great Theodolite. There are, I believe, not more than four in existence of that size—one by Ramsden, with which the greater part of the principal triangulation of Great Britain was executed, the two Indian instruments, and the one now before the Society.

Of the two Indian instruments, one was made by Messrs. Troughton and Simms about forty-five years ago, its Horizontal Circle bearing divisions cut by the hand of the celebrated Edward Troughton himself. The other was constructed and divided in India by the late Henry Barrow, then attached as instrument-maker to the Survey, its design being the work of the late Sir George Everest, then Surveyor-General of India. There are also in use with the Department several theodolites of 2-feet diameter, and of course many of smaller sizes.

The principles of construction, the advantages, and the defects of all these instruments were a constant theme of discussion to the officers of the Department, who being accustomed, according to the excellent system of the Great Trigonometrical Survey of India, to take every observation personally, have thereby at all times been led to display the most critical fastidiousness in every thing relating to the apparatus with which use has made them perfectly familiar.

Sir Andrew Scott Waugh, R.E., F.R.S., then Surveyor-General of India, having collected all the experience of his officers, including of course his own, gathered during many years of actual work in the field, combined the whole into a "*Project and Specification of a new Great Theodolite,*" which in 1855 he placed in my hands for the purpose of guiding me in the preparation of a design, with working drawings and a fully detailed specification. The project in question fixes all the general principles intended to be kept in view, and is ample for that purpose; but it enters into very few details, merely pointing out what is required, without definitely stating how it is to be attained, and it contains no drawings whatever, and only three or four slight diagrams. The part I had taken in the previous discussions had supplied me with a knowledge of the desiderata not actually described, knowledge which of course was also in great measure derived from the fact that I had worked for five years with Troughton's Great Theodolite, and subsequently with other excellent instruments.

At the time the task of executing this design was entrusted to me, I was commanding a party of the Great Trigonometrical Survey engaged in carrying a chain of principal triangles along the eastern coast of the Peninsula, a work known as the "Coast Series." I at once, during such leisure as I could snatch from these primary duties, began the design; but I soon found that it was quite impossible to do justice to so difficult a task whilst the mind and time were engrossed by matters of more pressing urgency, and of at least equal difficulty and importance. Short and broken periods did not admit of the continuity of thought and attention that were indispensable, and the work made very slow progress, besides needing constant revision in consequence of oversights and omissions caused by such desultory application. This will be understood, by any one who has gone through the same process, when I mention that the conception I had formed of my task was that I should execute, in the most minute detail, working drawings to scale of every part of this complex structure, in plan, section, and elevation, accompanied not only by an ample written descripton of every part, but also an explanation of the grounds on which the numerous novelties introduced had been adopted; so that when the whole was in the maker's hands, he need do little more than reproduce the drawings in metal by simple measurement, turning to the specification in all cases of doubt. The intention was that the whole should be sent home to be executed without any personal superintendence by the designer.

In April 1857, being at work in the Goomsoor Hills, a notoriously unhealthy tract, I was struck down by jungle-fever, being nearly the last of my camp of about 200 followers, only one of whom escaped, to succumb to that dreadful malady. A few months afterwards I was sent, under medical advice, to the Neilgherry Mountains for the recovery of my health; this gave me the leisure requisite for my design, which otherwise I might never have enjoyed. For several months I did little else but work at my drawings, which I now offer to the notice of the Society. One of these alone, the complete vertical section, occupied me nearly incessantly about three months, involving as it did the reconsideration of every other drawing in order to render the whole consistent.

At the expiration of my leave on medical certificate, the design, though very far advanced, was not complete; I had to lay it aside to resume my ordinary field duties on the Coast Series triangulation. In 1869, on my promotion to a regimental majority, I quitted the Survey in accordance with the regulations of the service, and, after twenty-six years' continuous residence in India, returned to England. Feeling a natural reluctance to leave the completion of my design to other hands, and, indeed, doubting whether any one unacquainted with my views could have completed it satisfactorily, I took it with me, hoping to finish it, as I ultimately did, at home, after my retirement from the army.

In 1862 I was directed oy the Secretary of State for India to superin-

tend the carrying out of this design and that of the other instruments already enumerated.

It is now ten years since the work was placed in the hands of Messrs. Troughton and Simms—a long period certainly. The delay has arisen from several causes—from the removal of the factory of that firm to Charlton, from the necessity for various modifications and some experiments, particularly on aluminium bronze as the material for some portions of the instrument, from the time occupied in the designing, supervising, and testing the other numerous and important instruments which I have enumerated, and, finally, from the time which my duty of superintending the whole scientific instrument supply of India necessarily occupies.

I cannot here attempt a full description of the instrument. I trust that such a description may at some future time be executed by myself, or by some officer of the Survey Department; but, for my own part, the leisure necessary for such an undertaking, although all the necessary materials are at hand, is denied me at present.

I will, however, indicate some of those salient features which may be rendered intelligible without illustrative figures.

The principal dimensions are as follows :—

Horizontal Circle.—3 feet in diameter, divided on silver to 5′, and read to tenths of a second by five equidistant micrometer microscopes.

Vertical Circle.—2 feet in diameter, similarly subdivided by two micrometer microscopes for ordinary terrestrial work ; but by four, whose positions can be shifted, for astronomical work.

Telescope.—Aperture 3·25 inches ; focal length 36 inches ; supplied with two distinct eye-ends, carrying respectively a vertical and a horizontal parallel wire micrometer, and furnished with both bright and dark field illumination.

Vertical Axis.—A truncated cone of steel, base downwards, 10·6 inches high, and 3·31 inches and 2·06 inches in diameter at the base and summit respectively, the flange being 4·4 inches in diameter, and of the "isolated" form described by me in the Royal Astronomical Society's Memoirs, vol. xxxi.

Horizontal Axis.—13·18 inches between the shoulders of the pivots, cast in one piece of gun-metal with steel pivots.

The Vertical-Axis socket and the five Horizontal-Microscope arms are cast in one piece of aluminium bronze.

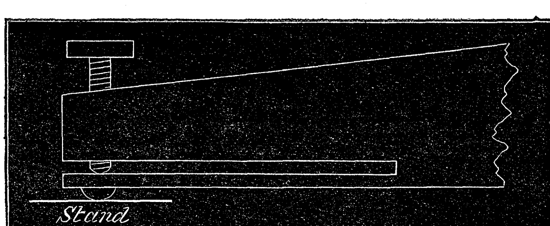
The Stand has three massive mahogany legs, braced together with horizontal and oblique bars of wrought iron, wooden braces having been found, in great hygrometrical changes, to impart azimuthal disturbance. I believe this to be the first stand for such instruments in which the means for levelling approximately are completely worked out. Within each leg, divided vertically for that purpose, is a long very substantial square-threaded upright screw actuated by a ratchet-wheel and endless screw, and capable of being immovably clamped, after adjustment, at points 15 inches asunder. On the upper conical ends of these three screws rest

three inverted radial grooves formed in the lower surface of a massive cast-iron circle, which is thus supported by the three elevating screws without being attached to them, and which is therefore able to accommodate itself to expansional changes without restraint. The upper surface of the cast-iron circle is turned flat and true, and receives the three feet of the instrument. It has three lateral screws for centering the instrument over the station-mark, as in existing large theodolites; it has also three rollers, capable of being pressed upwards by strong spiral springs thrown in and out of action by a cammed lever, this arrangement, already in use elsewhere, being intended to facilitate the setting of the horizontal zero.

The Feet-screws.—These are, as usual, three in number; no part of such instruments has been so entirely neglected as this. Whilst the Circles, Micrometers, and Levels indicated fractions of a second of arc, the foot-screw remained so coarse and primitive in form that the due levelling of the instrument was a matter of tedious difficulty, accomplished after all by a sort of adroitness helped by accident.

The first desideratum was that all clamping of the foot-screw after adjustment should be rendered unnecessary, since no clamping arrangement hitherto tried could be used without disturbing the level after adjustment. What was wanted, therefore, was that no azimuthal deviation of the mass of the instrument should ensue from an unclamped foot-screw, however loose.

The idea, as it presented itself to my mind, was that the effect which would be produced by vertical expansion of the end of the tribrach should be imitated if possible. After much thought I realized this idea by a very simple contrivance, the principle of which the annexed diagram will make plain. The tribrach arm is slit horizontally near its lower surface. This leaves a kind of long flat tongue of metal, which, being of considerable width, has great horizontal rigidity, but, being comparatively thin, is easily bent vertically. The outer end of the tongue rests on the stand; the foot-screw passes through the solid upper part of the tribrach, but not through the lower tongue.



It is evident that when the screw is turned inwards with the screwing-motion, the solid end of the tribrach will be raised, the slit being widened by the vertical yielding of the tongue, and *vice versâ*. But since the end of the screw does not rest on the stand, but on an intermediate plate or tongue, which is actually a portion of the tribrach itself, it is clear that if a lateral force be applied to the tribrach, no motion will be caused thereby, however loose the screw may be, so long as that force is less than the lateral rigidity of

the plate or tongue. The lateral force generated by turning the instrument in azimuth, when taking observations, is greatly within this limit. This arrangement may be found useful in other cases. It is perfectly successful; but it is only available where a moderate range of vertical movement is needed. In the present instance, as the stand on which the instrument is supported is always first made sensibly level, the vertical range of the foot-screw need not be more than $\frac{1}{100}$ of an inch; but in practice this is capable of being extended, without fear of injury to the parts, to about $\frac{1}{10}$ of an inch.

In the actual construction, the tongue above described as formed by slitting the tribrach, is, in fact, a separate plate, similar in plan to the tribrach, and firmly bolted to the centre of the instrument.

The second desideratum in the feet-screws was delicacy and certainty of action; this I attained by applying to them a clamp and tangent-screw arrangement very similar in principle to that sometimes applied to circles. Although the feet-screws themselves are very coarse, having about eight threads only per inch, the arrangement is such that one entire revolution of the slow-motion tangent-screw alters the level only one second of arc. Hence the foot-screw, though coarse and strong enough to bear the great weight imposed on it, is for the first time in keeping, in point of refinement, with the most delicate parts of the instrument.

The Horizontal Circle and its Micrometers.—The disposition of these most important parts has been the subject of much controversy. Two arrangements are possible:—(1) that called "the flying-circle" plan, in which the microscopes are immovably attached to the basis of the instrument, the circle revolving with the telescope; and (2) "the flying-micrometer" plan, in which the circle is fixed and the micrometers revolve. The question was carefully considered, and the balance of advantages appearing to be in favour of the second plan, that was prescribed in the project, and has been adopted. I have no doubt as to its superiority for instruments of this kind.

The horizontal circle is attached at the centre to the tribrach, and is elsewhere perfectly free.

The Guard Circle.—This addition was made to another instrument by Sir A. S. Waugh, late Surveyor-General, some time before the present design was commenced. I saw it subsequently in an Altazimuth by Brunner, of Paris, in the Great Exhibition of 1862. It was, I believe, arrived at in both cases quite independently. It consists of a second horizontal circle, exterior to and concentric with the circle carrying the working graduation already mentioned. There is a space of about $\frac{1}{10}$ of an inch all round between the two circles, and the upper plane of the outer guard circle stands about the same quantity above that of the inner principal or working circle. The guard circle has supporting radii of its own, quite independent of those of the inner circle. The guard circle has four objects:—(1) it protects the working circle from accidental injury; (2) it tends to distri-

bute changes of temperature uniformly over the circumference of the working circle; (3) it receives the clamp and tangent-screw, leaving the working circle absolutely free from contact at all times; and (4) it bears a strongly cut set of divisions, more visible to the naked eye than those of the working circle, which are exceedingly fine, and therefore inconvenient for setting the instrument approximately in azimuth.

Relieving Apparatus.—The moving parts of the instrument, namely, the pillars and their foundation-plate, the vertical-axis socket and horizontal-microscope arms, the telescope and the vertical circle, with its adjuncts, constitute a very ponderous mass, weighing 284 lbs.* If the whole of this great weight were allowed to bear on the flange of the vertical axis, the friction would be so great as almost to cause cohesion. To obviate this in similar cases, as in that of Troughton's Great Theodolite, internal rollers were introduced, pressed upwards by means of spiral springs against the lower surface of the moving mass. But this arrangement was imperfectly carried out in Troughton's instrument; and it is clear that at that time the action of such an antifrictional apparatus was not fully understood. There were three soft brass rollers with central holes revolving on axes fixed immovably in a circular ring, which ring was pressed upwards by three spiral springs.

The late Sir George Everest, in his work on the 'Measurement of the Meridional Arc of India,' p. cvii, states that when the instrument was first received "angles taken with it could not be depended on to within 50 seconds of the truth,"—a defect which was found to be mainly attributable to the inequality of tension of the three spiral springs, which exerted forces respectively in the proportions 8, 11, 15. Shortly after I joined the Survey Department, I, with the consent of its head, made a new set of rollers myself, the axes of which were fixed to them, instead of to the frame, the axes revolving in Y bearings. This improved the levelling of the instrument; but it was not possible, with every care, to maintain perfect equality of tension of the three springs; and this part of the instrument always caused anxiety.

The arrangement adopted for the present instrument is as follows:—The three rollers are of larger diameter than before, and they are of steel, finished with extreme care. They do not support the weight on their axes at all, but on their circumferences, precisely as is now customary with heavy revolving observatory-domes. The friction is therefore no longer of the rubbing, but of the rolling kind. The three rollers are connected, as in domes, by a light ring, which performs no function but that of keeping them equidistant. Means are also provided for restricting the path of the rollers to a circle perfectly concentric with the axis of motion of the instrument. Finally, the rollers are pressed upwards by no less than forty, instead of only three, spiral springs, by which multiplication a generally uniform tension is much more easily maintained, the mean tension of each spring

* This has been recently increased to 299 lbs. by additions.

being about 6·2 lbs., and of course $\frac{1}{40}$ instead of $\frac{1}{3}$ of the whole. An external deep groove, filled with oil, into which a thin circular rib dips, effectually excludes dust from the relieving apparatus and from the vertical axis.

The proper amount of relief has been a question much discussed. Sir George Everest, in his work above quoted *, fixes it, somewhat arbitrarily, at $\frac{3}{4}$ of the whole moving mass. This cannot be accepted as a general rule, because, if the mass were very great, $\frac{1}{4}$ of its amount might be sufficient to cause a most destructively abrasive action.

My method of adjusting the relief is as follows:—I assume that, for the purposes of horizontal angles only, the azimuthal motion cannot possibly be too free. I therefore first make the relieving force nearly equal the weight of the moving mass. Then I try the levelling of the instrument. With such excessive relief this is sure to be unsteady. I then cautiously diminish the relieving force until I obtain steady levelling. When I have done this, I know that I have given all the relief which is possible in the existing construction, consistently with the general purposes for which the instrument is required. In the present instrument the result stands thus:—

Weight of moving mass................	284 lbs. †
Relief (40 springs × 6·2 lbs.)	248 „

which leaves nearly $\frac{1}{8}$ of the moving mass active, instead of $\frac{1}{4}$, as prescribed by Sir G. Everest.

Horizontal Tangent-screw.—This, although apparently a mere subordinate agent, is really one of great importance and presenting some difficulties. There is always "loss of motion" in every screw unprovided with special means to prevent it. Loss of motion increases the difficulty of observation and also causes insecurity; for the tangent-screw is the link which connects the moving with the fixed parts, and the length of this link, once adjusted in observation, should be unalterable. Several methods of obviating loss of motion have been tried; and though many of them are suitable to small instruments, none have been quite satisfactory with large ones. The matter attracted great attention when I was in the Indian-Survey Department, and I was much engaged in studying it. The general conclusion I came to was that, however a spring might be applied, its tension ought to be constant and invariable. Hitherto this had not been the case, an ordinary *external* antagonizing spiral spring having been used, the compression of which was continually being varied by the action of the tangent-screw. It was found that after the observation had been made the spring continued to act, which was fatal to the observation. And the evil was brought home to this agent by the fact that in a particular instrument the springs attached

* Page cviii.

† Since this adjustment was effected, the weight of the moving mass has been increased by additions to 299 lbs., and the springs will have to be readjusted; but the *absolute* weight left active will probably remain nearly as at present.

to two different tangent-screws having been accidentally made to act in directions opposite to each other, the observation was disturbed in opposite ways.

In the present instrument I have adopted an arrangement which, I believe, is not new in principle, namely the "divided-nut" principle, sometimes used in machinery to prevent loss of motion. The block into which the tangent-screw is tapped is divided transversely, and the two halves are forced asunder, and therefore against the contrary sides of the screw-threads, by four *internal* spiral springs. The tension of these springs is necessarily constant, and therefore not subject to the disturbance and slow recovery of elastic force unavoidable in an *external* spring. Means are supplied for regulating the tension of the four springs, which must be a little in excess of the force necessary to move the revolving mass, without taking the parts to pieces. This arrangement I believe to be on the whole satisfactory.

Bubble-trier.—Experiments have constantly to be made to determine the angular value of the scales of levels of such instruments. Hitherto there have been no conveniences for this purpose. I have supplied a frame attachable at will to the telescope, on which the level under experiment can be laid, in order to compare its scale with the angular indications of the vertical circle.

Bearing of the Transit-Axis pivots.—Hitherto these have always been capable of adjustment in order to level the axis: but to this two objections exist:—first, there is always ground for fearing lest the adjustable parts should be left loose, in which case, owing to their distance from the centre of motion, they would be disturbed by the momentum generated in rotating the instrument in azimuth (since this would alter the relation between the telescope and the horizontal circle, observed angles would be vitiated to the extent of such disturbance); secondly, adjustable bearings must necessarily support the pivots at points and not surfaces, and consequently tend to wear them into grooves.

For these reasons the bearings are immovably fixed and finally adjusted by the maker by grinding. They are also of what is known as the segmental form, first introduced, I believe, by the Astronomer Royal when designing the great Greenwich Transit-Circle, a form which supports the pivot throughout its length and over a considerable surface, and which has been found at Greenwich to wear the pivots so equally that no sensible change in their form in the course of many years has been detected. Still the application of the non-adjusting principle to a large portable instrument must be considered as an experiment. Should the horizontality of the transit-axis undergo, as it may, a gradual change, the officers of the Survey will have to restore the adjustment by means of the grinder supplied with the instrument, an operation, no doubt, of some delicacy, even in the hands of an experienced mechanic, but which, I trust, nothing but accidental violence to the parts will ever render necessary.

Level Mountings.—The mode in which the levels are mounted was contrived by me, at the request of Sir Andrew Scott Waugh, then Surveyor-General of India; and I made the first example with my own hands, in about 1853, for Troughton's Great Theodolite. The same arrangement has since been applied to many other large instruments in India. Being rather a matter of detail, I shall here only say that its object is to remove, as much as possible, all restraint from the glass spirit-level, which should be allowed to adapt itself to changes of temperature with perfect freedom. The level is also encased in an external glass cylindrical cover, to protect it from sudden currents of air tending to alter rapidly the temperature of the parts. I believe that these principles were first applied by the Astronomer Royal to the Greenwich Altazimuth; but the details in my plan are somewhat different, and, as I venture to think, more complete. The appliances for adjusting the level in my plan are, I believe, new in their arrangement; my main object in devising them was to obviate strains, without introducing risk of shake, and to improve delicacy of action.

Material.—Whilst the instrument was under construction I became acquainted, at the Great Exhibition of 1862, with aluminium bronze, an alloy of 90 parts of copper with 10 parts of aluminium. Its properties seemed to be exactly those required for the material of such an instrument. With some difficulty, arising from the fact that no national establishment exists in England for such purposes, I got some experiments made on the alloy (partly by the makers, partly by the kindness of Mr. John Anderson, C.E., of the Woolwich Gun Factories *), which showed that the rigidity of the alloy might be taken at three times that of ordinary gun-metal. This being the most important property for my purpose, I determined on using it, and on reducing the thicknesses, not the depths, of all the lower parts of my design. This would still leave such parts twice as rigid as if constructed of the previous dimensions in gun-metal.

Accordingly the elevating screws of the stand and their bearings, the tribrach, horizontal circle, vertical-axis socket, horizontal-microscope arms, and foundation-plate carrying the pillars are of aluminium bronze. The remaining parts, having much less weight to bear, are of the usual materials, gun-metal and yellow brass, which are more easily worked than the bronze.

Probable performance of the Instrument.—The trials I have as yet made of the instrument lead to the conclusion that it is subject to no essential defect, and that the objects sought in its construction have been to a great extent attained. Actual work in the field, submitted to all the elaborate verifications indispensable in modern geodesy, can, however, alone ascertain its character; and this must be a work of years.

I now allude, as it may seem on first consideration rather prematurely,

* See my paper, Monthly Notices of the R. Astron. Soc., 14th Nov. 1862, vol. xxiii. No. 1, "On Aluminium Bronze as a Material for the Construction of Astronomical and other Philosophical Instruments."

to such a point for the purpose of guarding against undue expectations and of disclaiming excessive pretensions. The work that has been executed in India is of such a character, as attested by an enormous accumulation of results treated with absolute rigour, that, as respects some branches of it, I do not shrink from saying that improvement is scarcely possible. In respect to horizontal angles, the most important of all its branches, an elaborate investigation by Colonel Walker, R.E., F.R.S., the present head of the Survey, shows that the probable error of such angles, deduced impartially from a vast mass of materials, lies between $\pm 0''\cdot 28$ and $\pm 0''\cdot 20$, according as the circumstances are more or less favourable *. I believe that residual errors of that small amount contain hardly any instrumental or observational element, but that they are chiefly due to atmospheric disturbances, which no instrumental perfection can control.

As to vertical angles, the test of direct levelling compared with trigonometrical levelling, applied to a distance of 2700 miles, shows a difference between the results of these two independent methods averaging 7·3 inches per 100 miles, or $\frac{7}{100}$ of an inch per mile. There seems little room for instrumental improvement here.

In respect to astronomically determined azimuths, I hope the present instrument will give improved results, on account of the superior steadiness of level which I think it possesses.

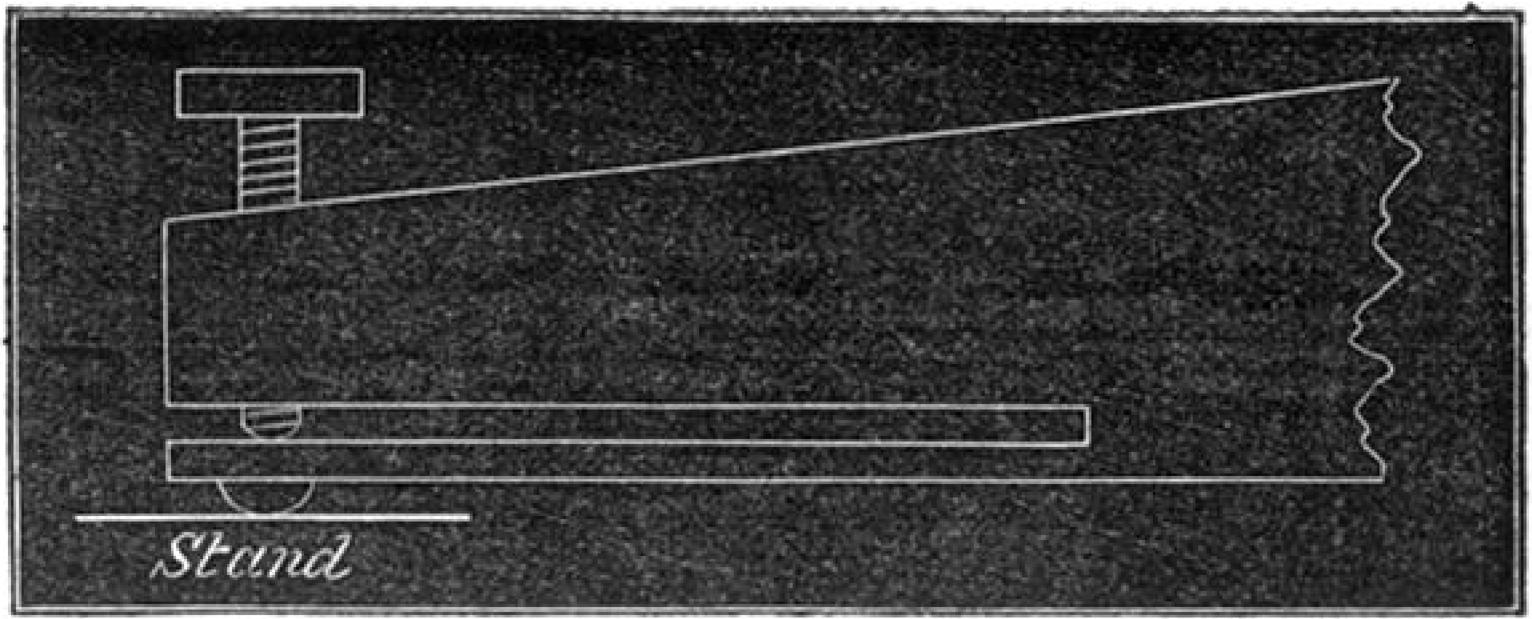
For the determination of astronomical latitudes it has more powerful and more complete vertical appliances than any former theodolite, and it should therefore give better results.

Finally, I believe it will be found to be more permanent in its adjustments, and more convenient both to adjust and to use, than any of its predecessors. To these points, as those which makers, not being observers, are peculiarly prone to overlook or mismanage, I have given the most earnest attention, knowing how indispensable it is that a man engaged in the most difficult and refined of all observations should be spared every anxiety and inconvenience which it is in the power of mechanical contrivance to prevent. If I have in some measure only attained this apparently humble object, I shall feel that the labour of years and the anxious ponderings of many a sleepless night have not been in vain.

II. "On some Elementary Principles in Animal Mechanics.—No. V. On the most perfect form of a Plane Quadrilateral Muscle connecting two Bones." By the Rev. SAMUEL HAUGHTON, F.R.S., M.D. Dubl., D.C.L. Oxon., Fellow of Trinity College, Dublin. Received April 3, 1872.

Let us suppose two bones, A B and A′ B′, lying in the same plane, joined by muscular fibres, and any two planes drawn through these bones inter-

* Account of the operations of the Great Trigonometrical Survey of India, by Col. J. T. Walker, R.E., F.R.S., &c., Superintendent of the Survey, vol. i. pp. 83, 84.


Stand