ACCOUNT

OF THE

NORTHUMBERLAND EQUATOREAL AND DOME,

ATTACHED TO

THE CAMBRIDGE OBSERVATORY.

By G. B. AIRY, Esq. M.A.
ASTRONOMER ROYAL,
LATE PLUMIAN PROFESSOR IN THE UNIVERSITY OF CAMBRIDGE.

CAMBRIDGE:
PRINTED AT THE UNIVERSITY PRESS.

M.DCCC.XLIV.

ACCOUNT

OF THE

NORTHUMBERLAND EQUATOREAL AND DOME.

In the month of August 1833 I was honoured with an intimation from the Duke of Northumberland (conveyed in the first instance through Sir John Herschel), that his Grace was desirous of presenting to the Cambridge Observatory an object-glass of nearly 12 inches in diameter, then offered for sale by M. Cauchoix, of Paris, if it should be judged to be good, and if it should be deemed a useful addition to the instruments of the Observatory. I lost no time in stating to his Grace the very great value which I attached to the possession of such a telescope; and I immediately received from him instructions to place myself in communication with M. Cauchoix. Considerable delay, however, occurred before the object-glass was sent to England; produced principally by an accident in Paris, which had nearly destroyed the object-glass. A large piece was broken out of one edge of the flint-lens, and it was necessary completely to re-work one surface. The object-glass, in a trial tube, was received at Cambridge on the 17th of December, 1834, and preparations were soon commenced for trying it upon stars. The object-glass at first (from an error in position) did not give a good image: and in endeavouring to avail myself of the assistance of a London optician of repute for its adjustment, I was deeply impressed with the imperfection of the methods usually adopted by opticians, and especially with the trouble and difficulty of applying them to a telescope 20 feet in length. I succeeded however in so far adjusting it, that on the 31st of May, 1835, I was able to report to the Duke of Northumberland that M. Cauchoix had fulfilled his engagement, and I immediately received his Grace's directions to close the arrangement with M. Cauchoix, and (after due communication with the authorities of the University of Cambridge) to proceed to take steps for mounting the telescope in the way which I should judge best.

During the time which had elapsed since I received the first notification of the intended present, my attention had naturally been turned to the different constructions adopted for domes, and the different forms of equatoreal mounting. I examined domes running upon fixed rollers without guides, domes guided by horizontal rollers, domes moving upon balls in square channels, domes moving upon chains of rollers,—and in all I found the difficulty of moving the domes, and the occasional liability to stick perfectly fast, to be so great, that I actually requested the Duke of Northumberland to permit me to mount the telescope in the open air. At length I had the good fortune to examine a dome turning upon free balls between concave channels (in the Observatory of E. B. Beaumont, Esq. Finningley Park, near Doncaster), and I was so much struck with the difference between its motion and that of any other dome which I had examined, that I began carefully to study the causes of this extreme facility of movement and total absence of jamming. I found that they arose principally from this circumstance: that any small alteration in the form of the dome (for instance, a change of the lower ring or curb from a circular to an elliptical form), or any small lateral disturbance (for instance, a displacement produced by the wind), is by this arrangement permitted to take place without introducing lateral friction, at the same time that the forces which are brought into action tend to restore the dome to its normal state and normal position. With this circumstance, another of less importance co-operated; namely, that there was no friction of axles, or (as in the chain of rollers) friction produced by incompatible movements. I had now no difficulty in undertaking to construct a dome which (though of a size equalled in only one previous instance) should move with perfect freedom. And I had seen in various instances, that a dome might be constructed of large dimensions without the use of curved wood (except in the curbs), and without difficulty in the management of the shutters. It was therefore determined to mount the telescope under a dome.

The position which I selected in the grounds of the Observatory is one which, though not unexceptionable, is extremely good. Its view is clear to the horizon, or nearly so, on every side, excepting an angle of azimuth of about 35° in the north-east, in which the principal building of the Observatory cuts off a part of the horizon. The only objections to this site are, that the ground is a little lower than that of the Observatory, and that the position of the dome is so near to the boundary of the Observatory-grounds, that it is exposed to danger from mischievous persons on the outside.

The selection of a form of equatoreal mounting was a matter of great anxiety. The first point to be determined was, whether the two bearings of the polar-axis should be both below the declination-axis (as in the mounting of the Dorpat equatoreal, and several of larger as well as of smaller dimensions since constructed, principally by German artists); or whether one bearing should be so far above the declination-axis, and the other so far below it, that the telescope could turn round in a meridian between them, (as in the Shuckburgh equatoreal at the Greenwich Observatory, the small equatoreal at the Cambridge Observatory, and many others). The former may for distinction be called the German mounting, the latter the English mounting. In comparing these, it must be remarked, that the German mounting necessarily implies (unless the axis be made extremely weak) that the diameter of the pivot at the upper bearing is extremely large; and the movement will therefore have a certain degree of stiffness. It also makes it impossible to use an hour-circle of large diameter, except when the axis is made very long, and the hour-circle is placed at its lower extremity: in this case, the connexion between the hour-circle and the telescope is liable to the unsteadiness of torsion of a long axis (unless it is very thick); or if the hour-circle is near the telescope, and therefore small, the most trifling imperfection of the clamps and slow-motion screws produces the most serious unsteadiness. The weight of a mounting of this kind, in consequence of the weight which is usually given to the axis, and the necessity for a counterpoise to the telescope, is (I believe) greater than that of a mounting in the English form for the same telescope. The telescope is necessarily placed on one side of the polar axis, so that both the bearings of the declination-axis are on the same side of the telescope; the bearing pivots are therefore very large: and the declination-circles and clamping-circles (in all existing specimens) are very small. Lastly, there is a practical inconvenience of the gravest kind: that when, during the observation of a celestial object, the object arrives at the meridian, it is necessary to turn the telescope on the declination-axis to the same polar distance on the opposite side, and to turn the polar-axis 180°; thus causing for a time a most troublesome interruption to the observations.

From all the objections which I have mentioned the English mounting is free. The pivots at the upper and lower bearings may be made small. The hour-circle and its clamping-circle may be made very large. The telescope may be mounted like a transit instrument between the two pillars or frames which are parallel to the polar axis, so that its pivots may be small, with any degree of strength for the middle of the declination-axis. The declination-circle may be extremely large. Lastly, there is no interruption to the continual movement of the instrument in hour-angle during the continuance of a series of observations.

It is possible to adopt the principle of placing the telescope between the two bearings of the polar-axis, but still to place the telescope on one side of the polar-axis, and a counterpoise on the other side. But in this intermediate form nothing is gained with regard to the strength of the polar-frame as respects torsion; and it is subject to the same inconvenience with regard to the size of the pivots of the declination-axis as the German mounting.

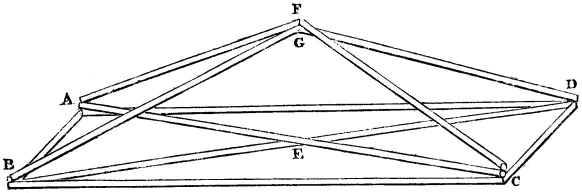
The only inconveniences or defects which I have been able to discover in the English mounting are the following. First, that as the polar-frame within which the telescope turns is necessarily somewhat longer and broader than the telescope, and as the supports for the upper bearing must be exterior to the polar-frame, theoretically a larger dome is necessary for the English mounting than for the German mounting. Practically, however, this inconvenience is nothing; for the dimensions of the dome of the Northumberland Telescope are not greater than are required for mere convenience. Secondly, that (except in such a case as that of the Armagh equatoreal, where the telescope turns within the hour-circle, a construction practicable only for small instruments), the declination-axis is necessarily at a distance from the hour-circle and its clamping circle; and any liability to torsion in the polar-frame produces the most serious unsteadiness of the telescope in hour-angle. This point requires the most careful consideration in planning the construction of the polar-frame.

In the English mountings of small instruments, the polar-frame has usually consisted of four or six parallel pillars connected at their extremities with equatoreal plates, by flanges of great breadth. The resistance to torsion depends here entirely upon the proportion which the diameter of the flange bears to the length of the pillar. The form of polar-frame which I judged most convenient for this large instrument, was one consisting of wooden rods (Norway fir-poles), whose diameters are very small in proportion to their lengths. The principle of resistance to torsion, which applies to small instruments, is not valid here; and it became necessary for me to consider upon what principle a frame can be constructed to resist torsion, on the supposition that the connexion of the rods, &c., is of the same kind as the connexion of two links in a chain, or rather as the connexion of the two members of a ball-and-socket joint.

Suppose now two parallel rods to connect the upper and lower equatoreal planes by ball-and-socket joints. For the purposes of this inquiry, we need not to consider the whole of the two planes, but merely those material lines in them which join the points of connexion with the rods. Our object now is, so to arrange that the upper and lower equatoreal planes shall necessarily turn together, or so to arrange that the four rods connected by free joints shall always remain in one plane. Or (calling the four angles A, B, C, D; A being opposite to C, and B to D,) so to arrange that D shall always remain in the same plane with A, B, C.

It is evident that this condition would be secured, if we could connect A and C by an inflexible rod, and B and D by another inflexible rod, and could thus firmly connect these two inflexible rods at their crossing, (which we will call E). For, the rod AEC being inflexible, E will always be in the same plane with ABC; and, the rod BED being inflexible, and B and E being in the plane of ABC, D will also be in that plane.

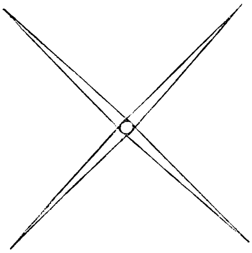
But, as the theory of framing implies that all rods are flexible to a small degree, we cannot absolutely adopt the construction just mentioned; but, retaining its principle, we can use the following, which is equivalent. Instead of a single rod, AEC, use a combination of three rods in a triangular form, AC, AF, CF, forming the triangle ACF; and in like manner, instead of a single rod, BD, use three rods, forming the triangle BDG; and connect F and G firmly together. Then it will be seen that the location of A and C in a certain plane determines the height of F, and therefore of *G*, above that plane; and the determination of the positions of *B* and *G* with regard to the plane, determines also that of *D* with regard to the plane; so that if once in it, it will always be in it. The following sketch represents the arrangement of rods in this, which may be considered the simplest anti-torsion construction.

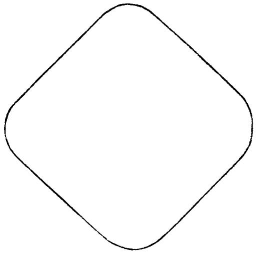


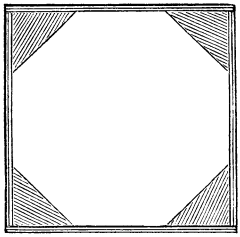
In the application of this construction to a frame of timber, a small modification is advantageous. It is difficult so to connect the ends of pieces of wood that they shall resist both pulling and pushing forces; and it is therefore necessary so to divide the strains, that the resistance to pulling forces shall be provided for by one connexion, and the resistance to pushing forces by another connexion. This can be done well by using another rod parallel to *AD* and *BC*, and passing through *F* and *G*, then inserting between it and *AD* and *BC* diagonals crossing *AF*, *BG*, &c., and giving to the diagonals no function except that of thrusting; the pulling together of the frame, so as to give firm bearing against the ends of these diagonals, being provided for by torsion-bands. In this manner the construction becomes a prism, consisting of three parallelogrammic sides, each side having cross-diagonals.

I have enlarged upon this subject because, though equivalent principles must have been adopted in many constructions, I have never seen them stated; and in communications with persons employed on, or familiar with the construction of instruments, I have never heard the subject of anti-torsion framing mentioned as one which they had ever contemplated. It is manifest, that, with due care in the application of this construction, any supposed difficulty in the English form of equatoreal mounting is completely removed. It will be found also that the adoption of this principle enables us to use rough workmanship, and to place it in the power of the observer to adjust the instrument, to make it firm, and even to change its form.

I had in several instances seen the convenience of adopting wood as the material for the construction of the telescope-tube, and had remarked its freedom from the quick tremors to which metallic tubes are liable. In constructing a temporary tube for trials of the object-glass, a singular appearance had presented itself, which I record here as likely to be instructive to others who may adopt the same material. The form of the tube was that of a square pyramid. On directing the telescope to a star, and adjusting the eye-piece to the position in which the principal image was a small point, this point was intersected by two crossing rays of great brilliancy, in the direction of the diagonals of the square tube. On pushing in the eye-piece, the broad cone of light, instead of being circular, had a square appearance, rounded at the corners. The following sketches represent these appearances. In order to discover their origin, I turned the flint-glass alone in its cell, the crown-glass alone in its cell, and both together; but the appearances remained absolutely unaltered. I was very much perplexed with this phenomenon; when at last, having by chance left the telescope several hours in the open air, I found that the rays had entirely vanished, and the cone of light was circular. It was evident from this, that the effect in question was produced by the warmth of the tube, when it was carried out from the warm room, in which it was kept all day, to the cold night-air. On considering the construction of the tube, I was led to the complete explanation. The sides of the tube were thin, and its angles were filled up with solid blocks; its general section being similar to the following:







The blocks at the angles remained warm when the sides had become cool, and a stratum of warm air was always in contact with their interior surfaces. The rays of light passing near them were therefore deflected too much towards the center. And this effect was greatly aggravated by the converging form of the tube, which kept a stratum of warm air close to these rays, through nearly the whole length of the tube. I would state, therefore, as a rule of prudence which ought to be followed in the construction of telescope-tubes, especially when made of wood, that the tube ought to be somewhat larger than the object-glass, that a conical or pyramidal form ought by all means to be avoided, and that there ought to be no remarkable difference in the thickness of the material on different sides of the tube.

I have already mentioned the difficulty which I had witnessed, and which in the autumn of 1835 I experienced in my own person, in the adjustment of the object-glass. This induced me to turn my attention to the construction of a mounting for the object-glass which should enable an observer at any time, while observing any star, to effect every possible motion of the two lenses of the object-glass.

Having witnessed the inconvenience and insecurity of a small declination-circle, and finding that a large one would cause far greater expense than I could sanction, and would give much trouble in its adjustment; I determined on adopting chord-rods (connected with the polar-frame) as the support of clamps, which would (by graduations on the chord-rods) give the means of setting for any celestial object; and which by connecting the clamps, not with the telescope-tube, but with the end of a long bar turning upon a pin in the side of the telescope-tube, near its centre of motion, would enable me to give a very convenient slow motion, combined with perfect firmness in declination, and would also give the means of accurately measuring small differences of declination.

The use of clamps for the hour-circle, connected with a slow-motion-screw, which requires from time to time to be wound back, is so inconvenient, that I could not entertain the idea of adopting it. Having once determined on using a complete circle for receiving the action of the clock-work, I perceived that there would be great advantage in making this circle separate from the polar-frame, and in clamping the polar-frame to it when necessary. For thus the circle may be considered as a part of the clock-work; it may always represent in position the celestial equator; and the register of the position of the polar axis with reference to the circle will always give the right ascension of the body observed. And the determination of the difference of right ascension of two neighbouring objects (one of the determinations for which the equatoreal mounting is particularly well adapted) becomes *in form* a separate determination of the right ascension of each, made without the observation of transits over wires.

In arranging the clock-work for moving the equatoreal in hour-angle, I had no hesitation in adopting the principle of regulation by friction, having seen several instances in which that principle worked exceedingly well. For one part, namely, the going-fusee, I was obliged to prepare a new construction. I happened to be present at the trial of a large equatoreal on a very critical occasion, when the spring of the going-fusee broke. I then perceived the necessity of using a going-fusee which required no spring: and arranged for this purpose the construction described by me in the *Cambridge Transactions*, Vol. VII. page 217.

On the observing-chair, and other parts of the apparatus, I have little to remark, except that I have endeavoured so to arrange the whole, that the observer when seated in his observing-chair, and alone, should, as far as possible, be able to command the motions of every part.

Several additions have been made by Professor Challis, which in the following description of details I shall endeavour to point out accurately.

I shall now proceed with an explanation of the Engravings.

Figure 1, Plate I., is a general plan of the Observatory and the Northumberland Dome, for the purpose of shewing their relative position. The scale is $\frac{1}{1440}$.

A is the portico and principal entrance to the Observatory, fronting exactly south.

B is the dwelling-house of the Director of the Observatory.

C is the apartments of the Assistants.

D is the Transit Room.
E the Circle Room.
F the entrance to the Northumberland Dome.
G, H, I, the boundary of the Observatory grounds.

Figure 2, Plate. II., is a ground-plan of the walls of the Northumberland Dome, shewing also, in projection on the horizontal plane, the south pier, the clock-work box, the south steps, the support of the north end of the polar axis, and the polar axis without the telescope. The scale is $\frac{1}{43}$.

A is the entrance door, exactly fronting the east.

B, C, are two ante-rooms.

D is the place of the window. This is the only window of the room: but, the inside of the dome being painted white, no necessity for other windows is felt.

E, F, are the two brick piers into which the two supports of the northern end of the polar axis are built. These piers are built upon foundations unconnected with those of the walls, and the piers are not at any part in contact with the walls. At the joining which is next the interior of the room the interstice is filled to a small depth with mortar, but with no hard material.

G,H, are two closets, formed by cutting off the two southern corners of the room.

It will be remarked that the plan of the walls is square, but that each of the side walls has (between its extremities) angular piers on the inside and corresponding pilasters outside. From these piers, arches are turned over the angles of the square room, so as to reduce it to an octagon, and these arches are filled up (leaving only a small recess) by the piers in the two northern angles, and by the closet-walls in the two southern angles. Similar arches, for ornament only, are turned in the wall on each remaining middle part of the four sides of the square. Thus the room, as seen from the inside, is a symmetrical octagon. The traces of these arches may be seen in Figure 67.

I, J, are the two wooden supports of the north end of the axis. They are common deals, 21 feet long, 11 inches broad, and 3 inches thick, with their edges turned exactly towards the center of motion of the telescope; they have been saturated with corrosive sublimate. They are built into the piers *E, F,* in a manner that will be described hereafter (Figure 36). Their lower extremities reach almost exactly to the angles of the piers *E, F,* at the level of the floor.

K is an iron triangle, connected by two projecting pieces (part of the same casting) with the two deals, and supporting the north end of the polar axis.

L is the inclined stone on which the south end of the polar axis rests. This stone is planted upon a brick pier, whose dimensions north and south are nearly the same as those of *L,* but east and west are about a foot larger on each side.

M is the iron box containing the clock-work which turns the equatoreal in hour-angle. Its dimensions are 2ft. 6in. by 1ft. 11in.: its height is 3ft. 4in.

N is a small plate, screwed upon the floor, and carrying the center-pin on which the observing-chair-frame turns in azimuth. (See *A* in Figure 60.)

O is the series of southern steps, intended for the support of the observer in the observation of low objects near the north, as the intervention of the polar-frame and its southern pier makes it impossible to turn the observing-chair-frame to those parts of the room. It will be remarked, that the east and west sides of *O* are not symmetrical: the reason of this is, that the chair-frame carries a ladder on one side (see *L*, Figure 60), and it is therefore unnecessary to provide fixed steps for the part which that ladder covers.

P is the frame of the polar-axis, supposing the telescope not inserted. Parts of this will be described in Figures 28 to 31, and 39 to 43.

The whole of the walls and piers are built in brick-work of the best quality. The northern piers *E* and *F* are cemented with Roman cement, and the southern pier (below *L*) is well grouted. The foundations on the south side are nearly ten feet below the floor: on the northern side they are much less. The thickness of the walls at the foundation is nearly three feet.

Figure 3, Plate I, is a plan of the top of the walls, shewing the wall-curb, the iron channel, the hold-fasts for securing the dome, and the fixed spikes for attachment of the machinery for slow motion of the dome. The scale is $\frac{1}{64}$.

AA is the external outline of the walls.

BB is the inner edge of the wall, where it is not covered by the wall-curb.

CC is the outer edge of the wall-curb.

DD is the inner edge of the wall-curb in those parts at which it falls within the angles of the walls. The form of the walls being octagonal (as described above), the circular curb is placed upon them in such a manner, that it somewhat overshoots the walls at the middle of each side of the octagon, and falls within them at each angle. The inner diameter of the wall-curb is 25ft. 8in.

EE is the iron channel, composed of 12 segments. Each segment is screwed upon the wooden curb by 8 screws on each side.

FF are the six free cannon-balls upon which the dome turns. Theoretically, three balls are sufficient: but practically, the slight yielding of the various parts of the dome will keep six balls in action, and then the frame of the dome will be less strained than if the bearings were upon a smaller number. The arrangement of the channel and balls will be seen in section in Figure 6.

GG are the four hold-fasts of the dome. Their construction will be explained under Figure 17.

H is the lever for ordinary quick motion of the dome, represented in Figure 14.

II, &c. are the pins to which the rope connected with the slow-motion-machinery of the dome is attached. One of these is seen at *O* in Figure 16.

Figure 4, Plate I, represents the mode of connecting the wall-curb with the wall.

AA is a bond-timber in the wall, at each angle of the octagon. Its whole length is about two feet on each side of the angle, its breadth nine inches, and its thickness three inches. Its upper surface is eighteen inches below the top of the wall.

BB are upright posts of the same section as *A*, at the distance of eighteen inches from the angle, securely connected with *AA*.

CC is the wall-curb, firmly connected with *BB*.

Figure 5, Plate III, is a plan of the lower dome-curb. Its diameter is the same as that of the wall-curb. The scale of the figure is $\frac{1}{64}$.

AA are the feet of the principal posts in one of the principal lines of beams.

BB are the feet of the posts in another principal line, parallel to the former.

It will be remarked that these posts, on one side, project beyond the external edge of the curb. This is the side on which the dome-shutters are placed; and this projection is for the purpose of giving hold for the hinges, and for making the shutter-openings water-tight.

CC are the feet of the posts in another principal line, transverse to the former.

The feet of the small uprights will be seen marked on the curb. Their number is twenty-eight.

The dimensions of the principal posts are 5 by $1\frac{1}{8}$ inches, excepting those which correspond to the shutter-openings, which are $8\frac{3}{4}$ by $1\frac{1}{8}$ inches. The dimensions of the smaller posts are 3 by $1\frac{1}{8}$ inches. The clear space between *A* and *B* is 29 inches, and this is the clear shutter-opening.

Figure 6, Plate III, is a section of the lower dome-curb, its iron channel, the wall-curb, its iron channel, and a cannon-ball between them. The scale is $\frac{1}{12}$.

A is the lower dome-curb. Its breadth is $8\frac{1}{2}$ inches, and its depth is $2\frac{1}{2}$ inches. It is made in two thicknesses, each thickness consisting of 12 segments, and these are laid so as to break joint with each other, and with the segments of the iron channel. The wood is fir.

B is the iron channel, with side-flanges, by which it is screwed to the wooden curb. The breadth of the concave channel is 6 inches, and its radius of curvature is nearly 7 inches.

C is the exterior, and *D* the interior of the wall-curb. It is similar to *A*.

E is the iron channel of the wall-curb, cast from the same pattern as *B*, and in all respects similar to it.

F is one of the cannon-balls, of $5\frac{1}{2}$ inches diameter.

G is one of the spikes fixed in the interior of the dome-curb, to receive the action of the lever by which the dome is turned in its ordinary quick motion, as will be shewn in Figure 14.

Figure 7, Plate III, is a plan of the upper curb of the dome to the same scale, $\frac{1}{64}$, as Figure 5: exhibiting the places where the tops of the posts reach its lower surface. It will be remarked that the interval between *A* and *B* is the same as in Figure 5, these two principal lines being strictly parallel. The intervals between the other posts are diminished, in consequence of the diminution of the diameter of the circle. A portion of this curb is completely cut away, to leave the shutter-opening perfectly clear.

Figure 8, Plate III, is a plan of the upper surface of the same curb, shewing the feet of the rafters of the upper cone of the dome. The dimensions of the six principal rafters are the same as those of the six principal posts (see Figure 5); those of the smaller rafters are $3\frac{1}{4}$ inches by $\frac{3}{4}$ inch.

Figure 9, Plate III, is a section of the upper curb, to a scale of $\frac{1}{12}$. The breadth of this curb is 10 inches; its depth is $2\frac{1}{4}$ inches; it is made of American birch, in three thicknesses.

Figure 10, Plate IV, represents the two curbs and the principal posts and rafters as united. The letters *A*, *B*, *C*, are applied in this figure to the same parts as in Figures 5, 7, and 8.

The permanency of form of the dome, so far as it depends upon framing at all, depends entirely upon the pieces represented in this figure. They are therefore connected with much care. Where the six posts and six rafters meet the lower curb and the upper curb, they are connected by knee-pieces of strong plate-iron, which are bolted to the wood-work by bolts passing through and taking hold of iron plates on the opposite side. On the side of the shutter-opening, where the posts *A* and *B* unite with the rafters *A* and *B*, they are connected by flat plates of the proper form. The transverse principal rafters *C* are united with the rafters *A* and *B* in the same manner; and the horizontal part *CC*, which is between the two lines *A* and *B*, is connected with them by a single plate of iron on each side, which, being bent at both ends, applies to *A*, *B*, and *C*, and is bolted to all. The angles of the three lines of *A*, *B*, and *C*, are also strengthened by bars of iron, which are forked at each end to embrace the wood-work, and are bolted to it by bolts passing through all.

It must be remarked that the rafters *C* are not in the same plane with the posts *C*, or are not in a vertical plane. In order that the telescope may command all parts of the heavens, it is necessary that the shutter-opening should be carried nearly a foot beyond the center of the dome. This defines the place of the horizontal part *CC;* and the rafters *C* are inclined, to meet the rafters *A* and *B* at the same point, so as to make *CCCCC* a continuous line. This may be seen in Figure 67.

Figure 11, Plate IV, represents the frame of the dome, with all its posts and rafters mounted. The rafters in each half of the upper cone converge to the conical point on that side; some of them being cut to allow the principal rafters *C* to retain their inclined position. On the side opposite the shutter-opening, there is one small rafter between the principals *A*, *B*, and parallel to them.

Figure 12, Plate IV, represents the frame as strengthened by the intersecting hooping-iron. The hooping-iron used for this purpose was the lightest that could be procured. I have no memorandum of its weight, but I believe that it was 4 ounces to each foot of length. Each of the hoops is secured to every one of the posts or rafters which it crosses, and its ends are turned under the lower curb, and over the upper curb, and there secured fast. This structure gives to the dome a degree of strength with lightness, which probably could be obtained in no other way.

The dome is covered with plates of zinc, which are laid upon beads fixed on the posts and rafters, in the manner in which plates of zinc are usually laid, so as to permit the thermal expansion and contraction of the metal. Each plate is also secured to the intersections of the iron hooping by small loops of zinc, shewn in this figure.

The frame of the dome was built together with the upper curb forming a complete circle, and the part of the upper curb interrupting the shutter-opening was then sawn away. I had thought it probable that the thrust of the rafters of the upper cone would have forced the upper curb into a portion of a larger circle; but on the contrary, the shutter-opening was diminished by a small fraction of an inch.

The stiffness of the frame is shewn by this circumstance. One of the six cannon-balls is smaller than the others by about $\frac{1}{12}$ of an inch in its diameter, and the dome-frame does not always yield sufficiently to press upon this ball.

Figure 13, Plate V, is an east and west section through the walls and the dome, exhibiting also a view of the polar-axis without the telescope.

AA are the walls.
B is the entrance-door from the passage between the two ante-rooms.
C is the wall-curb.
D, *D*, are the cannon-balls.
E is the lower dome-curb.
F is the upper dome-curb.
G is the upper shutter, taken in section just across the two vertices of the upper cone in Figures 10, 11, 12, or in the line *AB*, in Figure 21.
HH are the two piers into which the supports of the northern end of the polar-axis are built, corresponding to *E* and *F* in Figure 2.
II are the two deals for supporting the northern end of the polar-axis, built into *HH*; they correspond to *I*, *J*, in Figure 2.
KKK is the iron triangle at the top of the deals, corresponding to *K* in Figure 2.
LL are iron braces, strengthening the deals.
M is the southern steps, corresponding to *O* in Figure 2.
N is the stone on which the support of the lower end of the polar-axis rests.

O is the box containing the clock-work for moving the polar-frame in hour-angle.
P is the polar-axis frame.

Figure 14, Plate VI, is a view of the lever used for giving to the dome a quick motion.

A is the lower dome-curb.
B its iron channel.
C the wall-curb.
E its iron channel.
F is one of the cannon-balls.
G is an angle of the walls of the octagonal room.
H is an iron bar fixed into the bond-timber described in Figure 4, and strengthened by stays entering into other parts of the same bond-timber. It corresponds to *H* in Figure 3.
I is the lever, turning loosely upon the end of *H*. Its upper end is armed with iron; its lower end is at a convenient height for the application of the hands.
KKK are pins fastened to the inside of the dome-curb, corresponding to *G* in Figure 6.

To move the dome in either direction, the iron end of the lever *I* is made to press against one of the pins *K*. As soon as the dome has moved so far that the inclination of the lever is inconvenient to the hand, the iron end of the lever is disengaged from that pin, by pressing the lower end of *I* towards the wall, and then the iron end is made to press against another pin *K*. The dome is thus made to revolve with great rapidity, by very small exertion of the arms.

The motion of the dome appears at first very singular. When the force of the lever is applied to one of the pins *K*, that part of the dome begins to move instantly, but the part opposite to it does not move at all for a short time, and the intermediate parts move transversely to the channel at those parts. (The facility of moving the dome depends entirely upon this transversal motion; for, in whatever way the dome is mounted, the effort to take transversal motion at those parts is the same; and if the mounting were of such a nature as to resist that transversal motion, it could make its resistance effective only by introducing a strong lateral pressure upon the dome, which would be accompanied with considerable friction). The curved form of the channels, however, gives the dome an immediate tendency to resume its proper position at those parts, and this tendency causes the opposite side of the dome to progress. The irregularity of motion is lost in two or three seconds of time.

In the construction of the iron channels, I omitted to give directions that holes should be made in a few places for draining off the water which is occasionally deposited in them. In general the water produces no inconvenience except the oxidation of the surface: but in the winter the water becomes frozen, and the ice offers a sensible resistance to the motion of the dome.

Figure 15, Plate VI, is a plan, and Figure 16, Plate VI, is a perspective view, of the apparatus by which slow motion is given to the dome. The same letters apply to both.

A is the long shaft of a handle for turning the wheel-work. This shaft is tubular, having a long slider within it, whose end is connected with *D*. By means of a groove along the slide, and a stud projecting into it from the tube, the slider and the tube are made to turn together. The length from *B* to *D* is about 6 feet 6 inches, when the slider is thrust in close: but when it is drawn out to the utmost, the length is nearly doubled.

B is a loose tube of wood.

C is the winch. In turning the shaft, *B* is held in the left hand, and then becomes a center of motion while the winch *C* is turned by the right hand.

D is a universal joint.

E is a pinion, working in the bevelled wheel *F*.

G is a pinion on the same axis with *F*, working in the wheel *H*.

I is a barrel connected with *H*.

K is a latch for keeping the wheel-work in gear. On lifting *K*, the spindle carrying *F* and *G* can be drawn to the front, so as to disengage those wheels from the others.

L, *L*, are two pullies fixed to the dome.

M, *M*, are two ropes fastened to the barrel *I*, and passing from it in opposite directions round the pullies *LL*. By turning the wheel-work, therefore, one of these ropes is relaxed, and the other is stretched.

N is a small plate, with a hole in its center, and rings at its ends. The two ropes *MM* are permanently fastened to the two end-rings of *N*. When the machinery is in use, the hole of *N* is slipped upon *O*, one of the pins fixed to the wall-curb or wall-plate.

O is one of these pins, corresponding to *IIII* in Figure 3.

P, *Q*, and *R*, are holdfasts by which the frame of the wheel-work is fixed to the dome.

It will be seen, therefore, that the wheel-work and the two pullies *LL* travel with the dome, and that the pin *O* and the piece *N*, which for the time is fastened to it, are fixed to the wall. Consequently the turning of the barrel *I* by means of the winch *C*, as it alters the relative position of *L* and *N*, will make the dome revolve. This apparatus answers in all respects the same purpose as the ordinary clamp and slow-motion-screw in astronomical instruments: there is just friction enough in it to hold the dome still, but by turning the winch *C* the dome may be moved slowly with very great ease. The winch *C* is carried to the chair of the observer; and thus in a long scrutiny of the same object he can, without leaving his place, turn the dome to follow the object.

Figure 17, Plate VI, is a perspective view of one of the hold-fasts for securing the dome when no observations are going on. There are four hold-fasts; their places are marked in Figure 3 by the letters *GGGG*.

AA are two supports fixed in bond-timbers.

B is a strong support, well fixed to the dome-curb.

C is the vertical shaft.

D is the winch by which it is turned.

E is a hook for preventing *D* from being turned out of position by accident, or by the shaking of the dome.

F is a mushroom-head, consisting of two short cylinders; the upper is the broader, being $5\frac{1}{2}$ inches in diameter; and both are eccentric. When the hold-fast is in the position represented in the figure, (which is the position for securing the dome) the upper cylinder presses upon the top of the dome-curb, and the lower cylinder presses the inner side of the dome-curb.

G is the dome-curb.

The use of this apparatus is to prevent the dome from receiving a small oscillatory motion. The dome is moveable on its balls, either in the direction of its revolution, or in a direction which (at certain parts) is transverse to the channel, by a very small force. If a motion of the latter kind be communicated to it, it speedily returns; but then, as in other cases of oscillation, if a force act by impulses nearly following the periods of oscillation of the dome, a very great motion may be given to it, which no obstacle could stop, and which will end by throwing the dome and the balls completely off the walls. A very small resistance, however, is completely sufficient to prevent the first small motion from being given to it. This resistance is supplied by these four hold-fasts.

In the heavy gale of the 23rd January 1836, when the dome was nearly finished, but before the hold-fasts were constructed, the dome was blown about 7 feet from its proper position, and was only saved from being completely carried off by lodging upon one of the deals *I* in Figure 13. Since the hold-fasts were constructed, it has been exposed to many gales without the smallest appearance of danger.

Figure 18, Plate VII, is a horizontal section across the lower shutter, on a scale of $\frac{1}{16}$, to shew the arrangement of the irons by which it is opened and shut from the inside. It is to be remarked that there are only two shutters: one extending from the lower curb to the upper curb, and the other extending from the upper curb to the extremity of the shutter-opening; and that both shutters turn on hinges in the manner of doors. Figure 18 supposes the shutter closed.

A and *B* are the two principal posts corresponding to *A* and *B* in Figures 5, 7, and 10.

C is the hinge-piece projecting from *B*.

DE is the shutter, which is merely a frame crossed with hooping-iron and covered with zinc-plate.

F is the hinge-piece for the interior iron, fixed to *B*.

G is the iron which turns on *F*.

HI is an iron which is jointed at *H* to *G* and at *I* to the shutter.

K is a rope for securing the shutter when closed.

L is a sort of pyramid of four wires, attached to the shutter in order to prevent its tension.

The same description would apply to the upper shutter, supposing the section perpendicular to its plane.

Figure 19, Plate VII, is a section of the same shutter supposed to be wide open. The same letters apply to this figure as to Figure 18. On comparing these two figures, it will be seen that the movement of opening is effected by giving a movement of turning to the bar, whose pivot is at *F*, (but whose projection on the section is concealed by the hinge-piece *F*), to which the iron *G* is attached. The moving apparatus is thus entirely within the dome. The form given to the shutters makes them perfectly water-tight.

The only inconvenience attending this construction is that the shutters, being when fully opened in a position nearly at right angles to the side of the dome, are exposed to the wind; and that, if the dome is not secured either by the holdfasts described in Figure 17, or by the machinery described in Figure 16, it may be carried round by the wind: in which case any dependent handles, &c. of the dome would pull down or greatly injure any thing of which they might take hold. No inconvenience has been felt from this circumstance, as the most ordinary caution is sufficient to prevent it: and in the high winds which might more seriously endanger the shutters or dome, the state of the sky is such that there is no possibility of making observations. Nevertheless, if I had occasion again to construct a dome of large dimensions, I think that, at the risk of losing some of the advantage of perfect dryness which is given by this construction, I should endeavour to make the shutters slide laterally. This may be done without great difficulty, by attaching a rack to the upper edge of each shutter and another to its lower edge, and causing two pinions to work in these racks, these pinions being upon the same spindle, which spindle should be parallel to the shutter-post and as close to it (within the opening) as it could be conveniently placed.

Figure 20, Plate VII, represents the form of the upper shutter. The shorter part covers that part of the opening which is beyond the center of the dome. The hinges are both in the longer part.

Figure 21, Plate VII, is an interior view of the two shutters, to shew the arrangement of the irons for opening them (omitting the lower parts of those irons, the check upon the order of opening the shutters, and the wheel-work.)

AAA is one of the lines of principal posts and rafters.

BBB is the other, parallel to *AA*.

CCC is that which is transverse to them.

D is the interior spindle of the lower shutter, (whose projection is concealed at *F* in Figures 18 and 19.)

E is the interior bar (corresponding to *G* in Figures 18 and 19.)

F is the jointed iron (corresponding to *HI* in Figures 18 and 19.)
G is the lower interior spindle of the upper shutter.
H is a strong universal joint.
I is the upper interior spindle of the upper shutter, connected with *G* by the joint *H*.
K is the interior bar (corresponding to *G* in Figures 18 and 19.)
L is the jointed iron (corresponding to *HI* in Figures 18 and 19.)
M, *M*, are counterpoises for the weight of the upper shutter.

The movements of the two shutters thus depend on the turning of the two spindles *D* and *G*, which are parallel and only a few inches apart.

Figure 22, Plate VII, is a view of the lower part of the interior spindles *D* and *G*, and of the machinery connected with them.

A is the dome-curb.
B, *C*, are hold-fasts for the frame of the machinery.
D is the interior spindle of the lower shutter.
E is the top of the corresponding spindle of the wheel-work, shaped into four small projections, to take hold of the T-head at the end of *D*, and to admit of being detached easily.
F is a crooked bar attached to *D*, being part of the apparatus by which the order of opening and shutting the two shutters is determined: (to be described in Figures 23, 24, 25.)
G is the lower interior spindle of the upper shutter.
H is the top of the corresponding spindle of the wheel-work.
I is a crank-shaped projection of *G*, being part of the apparatus affecting the order of opening the shutters (Figures 23, 24, 25.)
K is a latch to prevent the pieces *F* and *I* from moving from their present position (which corresponds to that of both shutters open). In order to close either of the shutters it is necessary first to lift the latch *K*.
L, *L*, are two universal joints for the attachment of the winch-shafts.
M, *M*, are two loose tubes of wood, to be held in the left hand as centers of motion, while the right hand is employed in turning the winches *NN*.

The wheel-work requires no particular explanation; it will be seen that, by virtue of its mechanical power, a small effort on the winches *N*, *N*, will produce a very great turning force on the spindles *D* and *G*.

The shafts *LM* are about 8 feet 3 inches long, between the universal joint and the loose tube, depending to a height which is convenient for the hands.

The bars *D* and *G* are about an inch square.

Figures 23, 24, 25, Plate VII, are intended to explain the effect of the projecting irons, *F* and *I*, of Figure 22, by exhibiting them (in plan) in different positions. It must be remarked that the lower part of the upper shutter completely covers the upper edge of the lower shutter, in order to shoot the rain off it. The upper shutter therefore must be always opened before the lower is opened. The upper shutter, however, can be opened without opening the lower. If any attempt were made to open or shut the shutters in a different order, they would infallibly be broken. It is proper therefore so to arrange the machinery, that the parts which are nearest to the hand cannot be moved in any other order than that which fulfils the conditions of opening the upper shutter before opening the lower, or closing the lower before closing the upper. The projecting pieces *F* and *I* effect this.

Figure 23 represents the irons in the position corresponding to both shutters closed. To open the lower shutter, the point of *F* must be turned downwards (on the paper), but this cannot be done, because it is stopped by the point of *I*.

Figure 24 represents the irons in the position corresponding to the upper shutter open, and the lower closed. *I* is now turned away, so that *F* can be turned.

Figure 25 represents the irons when both shutters are opened. The curved part of *F* has now wrapped round the crank-rod of *I* in such a manner that *I* cannot be turned back to the position of Figure 23 (or the upper shutter cannot be closed) until *F* is turned back (or the lower shutter is closed).

Figure 26, Plate VIII, is a general view of the building and dome from the north-east. The shrubs at the left hand are at the boundary of the Observatory grounds.

Figure 27, Plate VII, is a plan of the metallic work attached to the inclined stone which is planted on the south pier for the purpose of supporting the lower pivot of the polar-axis, on a scale of $\frac{1}{12}$.

Figure 28, Plate IX, is a plan of the polygon forming the lower end of the polar-axis, and of the large equatoreal circle, on a scale of $\frac{1}{12}$.

Figure 29, Plate IX, is a view of the polygon and the large equatoreal circle.

Figure 30, Plate X, is a view of a small portion of the polygon and equatoreal circle on a larger scale.

Figure 31, Plate X, is a section of the polygon, the equatoreal circle, the pivot of the polar-axis, and the support of the pivot.

The following explanation applies to all these five figures: the same letters corresponding to the same parts in all.

A is a plate of iron screwed to iron plugs in the stone. Upon the middle of *A* is a raised block, seen only in Figure 31.

B is an inverted dish, 18 inches square, which rests upon *A*, and carries the socket in which the pivot of the polar-axis turns.

CCC are eight screws, tapped in the sides of *B*, and pressing with their points against the sides of the raised block of *A*. By means of these, the socket of the lower pivot is adjusted in position.

DD are four screws tapped in the upper flat of *B*, and pressing with their points on the flat of the raised block of *A*, so as to tilt the socket a little, if necessary.

E is the socket-piece, screwed upon *B*.

F is the pivot of the polar-axis, $3\frac{3}{4}$ inches in diameter.

G is a screw in the side of the socket, of which no use has been made.

H is a friction-wheel, partly supporting the pressure of the pivot. Its axis is carried by a strong spring, concealed in the figure by the radii of the friction-wheel.

II are screws supporting the end of the spring.

KK are the radii of the polygon. The polygon is of cast iron; it is an irregular hexagon, its longest diameter being about 7 feet. The declination-axis is parallel to this longest diameter. The depth of the radii varies from 7 inches near the center, to 4 inches near the outside, and their thickness varies from 1 inch near the center, to $\frac{3}{4}$ inch near the outside. These are the thicknesses at the upper part; those at the lower part are less by $\frac{1}{4}$ inch.

LL are the sides of the polygon. Their depth is 4 inches, their thickness at the top about $\frac{3}{4}$ inch, and at the bottom about $\frac{1}{2}$ inch.

The artist who constructed the polygon was unable after repeated trials to cast it so that it would not break in cooling. One of the long radii in this is broken very near to the outside, but it is strengthened by knee-pieces in such a manner that (in the estimation of the workman) it is as strong as if it had been cast whole.

MM are the six cells for the reception of the feet of the poles forming the sides of the polar-frame. They are nearly six inches in diameter, and each has two small recesses at its sides for the bolts at the sides of the poles; these bolts pass through the bottoms of the cells.

NN are the twelve abutment-cells for the feet of the braces of the polar-frame. The position of these abutment-cells, as shewn in Figures 28 and 29, will indicate the planes in which the braces act.

OO are the radii of the equatoreal circle.

P is its flat limb, on which the graduations are traced. The diameter of its outer circumference is 5 feet 5 inches. It is made of bell-metal, and is cast in one piece. It is racked all round the edge, for the screw *Z*, which is driven by the clock-work.

Q is the clamping-ring of the circle, standing up perpendicular to its plane, to be grasped by the clamps *RR*.

RR are the two clamps. Only one was at first constructed; but Professor Challis found it convenient to apply another to the opposite side. These clamps are carried by the polygon, being moveable upon the shortest sides of the polygon by slow-motion-screws, and grasping the ring *Q* by means of clamping-screws.

SS are the clamping-screws.

T is the slow-motion-screw, which is tapped in a piece of metal carried by the polygon (attached to it by the screws *ee*, Figure 30) and presses with its point upon the clamp-piece.

U is the case containing the strong spiral spring, which drives the clamp-piece to bear against the point of *T*.

V is a bevelled-wheel-work, for the more convenient application of the hook's joint, by which the observer turns the slow-motion-screw *T*.

W is a micrometer-microscope, carried by the polygon, for reading and subdividing the divisions of the circle. This was attached by the direction of Professor Challis.

X is a spindle from the clock-work, which turns the screw *Z*.

Y is a screw-clamp, connecting *X* with the axis of the screw *Z*. It is of no use here.

Z is the screw which works in the racked edge of the equatoreal circle, and therefore gives a motion in hour-angle to it, and to the polar-frame, if either of the clamp-screws *S* is tightened.

a is the piece of metal, attached to the stone, which carries the clock-work-screw *Z*.

b is a small lever for putting the screw in or out of gear with the racked edge of the equatoreal circle.

c is the universal joint connecting the screw *Z* with the spindle *X*, through the intermediation of the clamp *Y*.

d (Figure 30) is the piece attached to the polygon-side, which carries the micrometer-microscope *W*.

ee are screws connecting the bearings of the slow-motion-screw *T* and spring *U* with the polygon-side.

f is the point of the clamp-screw *S*.

g is a reflector for illuminating the divisions of the great circle, as viewed by the microscope *W*.

h is a vernier carried by the polygon-side, for subdividing the divisions of the great circle; its use is in a great measure superseded by that of the microscope.

k (Figure 31) is a key passing through the great pivot, and sustaining the large equatoreal circle.

The use of the circle may now be explained. Suppose that, at the commencement of a series of observations, the clock-work is put in action, and the sidereal time noted. Then the screw *Z* ought to be detached from the racked edge; and the large wheel, freed from the clamp *R*, ought to be turned so that the reading of the lowest part of its divided edge is the same as the sidereal time, or so that the reading of the highest part (shewn on a small vernier carried by the plate *a*) differs 12^h from the sidereal time; and the screw *Z* ought again to be put in gear with the racked edge. Then the reading of the lowest part, as carried by the clock-work, will always be the sidereal time, or the right-ascension of the meridian; and therefore the reading of that part of the circle which may happen to be under the vernier *h*, will be the right-ascension of any body to which the telescope is directed. Thus the instrument gives at once the apparent right-ascension of any object without any observation of a transit. This gives great facility in setting for an object. And though the right-ascension may be in some degree in error (as well from the usual index-errors as from the flexures to which an equatoreal frame is liable), yet the right-ascensions of two objects within a few degrees of each other, will be affected sensibly by the same error. And by reverting from one object to the other (which is done with ease, because it is merely necessary to set the vernier *h* to the right-ascension of the object), even the small error in the speed of the clock-work is completely eliminated.

Figure 32, Plate XI, is a plan of the clock-work, to a scale of $\frac{1}{5}$

Figure 33, Plate XI, is a view, exhibiting more completely its regulating part.

Figure 34, Plate XII, is a view of the going-fusee; supposed to be detached.

As the same letters correspond to the same parts in these, they may be described together.

A is the iron box inclosing the machinery.

B is the iron frame which carries the machinery.

C is the frame forming a bent lever, which carries the pivots *HH* of the barrel, which gives abutment to the clicks *ss* that act on the internal ratchet *a* of the barrel-wheel, and which sustains the strain of the return *t* of the weight-line.

DD are the pivots of the lever-frame *C*, turning in the frame *B*.

E is the point at which the return *t* of the weight-line is attached to the lever-frame *C*.

FFF is the spindle of the winding-up-wheel *G*, turning in the frame *B*.

G is the winding-up-wheel. While the clock is going in its usual way, *G* turns in the direction indicated by the arrow; in order to wind up the clock, it must be turned in the opposite direction.

HH are the pivots of the barrel, turning not in the frame *B*, but in the lever-frame *C*.

I is the barrel.

K is the cord fastened to it and wrapped round it, and descending on the side nearest to *F*.

L is a toothed-wheel attached to the barrel, and working with the winding-up-wheel ***G***.

M is the barrel-wheel.

N is the pinion of the next wheel, driven by ***M***: the spindles of ***M*** and ***N*** being in the same horizontal plane.

We may here conveniently describe the action of the going-fusee. The weight *w*, by means of the pully *v*, exerts a tension both upon *t* and upon *u*. The latter acting on the barrel ***I***, which is prevented from moving with more than a certain speed by its engagement with the pinion ***N***, produces a certain pressure on the pivots ***HH***, which are carried by the horizontal arm of the bent lever. The former (the tension on *t*) exerts a strain on the inclined arm of the bent lever. The bent lever then will take a position in which these strains produce equilibrium. And this remains constant during the ordinary going of the clock; and as the barrel ***I*** revolves, driving the barrel-wheel ***M*** by means of the usual click *z*, the teeth of the internal ratchet *a* pass successively under the clicks *ss*.

Now as soon as the spindle ***F*** and the winding-up-wheel ***G*** are turned in the direction opposite to that shewn by the arrow, the motion of the wheel ***L*** is reversed, and the teeth of the small ratchet pass under the click *z*. As the circumference of the wheel ***L*** is as nearly as possible the same as that of the barrel at the place of action of *u*, it is evident that the upward action of the teeth of ***G*** upon those of ***L***, to such a degree as to lift the cord *u*, produces just the same effect on the barrel as if the strain of *u* were for the time annihilated. This strain being annihilated, the pressure upon the pivots ***HH*** is annihilated. Consequently, in the bent lever, the strain of *t* upon ***E*** immediately preponderates, and would instantly lift the pivots ***HH***. But as soon as that motion begins, the click *s* lodges in the teeth of the internal ratchet *a*; and ***E*** descends very slowly, lifting the pivots ***HH*** very slowly, without permitting the wheel ***M*** to turn relatively to ***C***, and continuing the action upon the pinion ***N*** by means of that lever-motion in which ***C*** and ***M*** move as in one piece. As soon as the winding-up-strain on ***G*** is relaxed, the renewed strain of *u* again exerts a pressure on ***H*** which preponderates over the pressure of *t* upon ***E*** (the effect of which is now somewhat diminished by the inclination of the bent lever) and the lever is thrown into its former position, and the clock goes on as before.

O is the second wheel on the same axis with ***N***.

P is the pinion of the third wheel, driven by ***O***.

Q is the third wheel.

R is the pinion driven by ***Q***.

S (Figure 33) is a contrate wheel, on the same spindle with ***R***.

T is the pinion of the ball-spindle, driven by ***S***.

U is a fly attached to the ball-spindle.

V is a screw at the top of the ball-spindle.

W is the wheel in which it acts; this wheel is attached to the spindle ***X***, (represented by the same letter in Figure 28), which carries the screw that moves the equatoreal wheel. Immediately below *V*, a small dish of oil is carried by the ball-spindle, to lubricate the teeth of *W*.

Y and *Z* (Figure 32) are the same as in Figure 28.

a is a small catch for pressing a gentle spring against the circumference of the fly, in order to stop the clock.

bb are the centrifugal balls.

c (Figure 32) is the universal joint on the spindle to the screw for the equatoreal wheel, as in Figure 28.

d is the forked extremity of a light lever, embracing the square spindle of the winding-up-wheel: its object shall be described under *y*.

e is a slider on the ball-spindle, which is raised by the spreading outwards of the balls *b*.

f is a forked lever, with pins projecting into a channel grooved round *e*.

g is the fulcrum on which *f* turns.

h is a bar by which *f* acts upon another lever *i*.

k is the fulcrum on which *i* turns.

l is a slider on the fixed bar *q*, supporting *k*.

m is a smooth wheel fixed to the ball-spindle, on the under-side of which the lever *i* exerts a pressure.

n is a counterpoise to the weight of the lever *i*.

o is a screw with graduated head, for drawing up the wedge-shaped piece *p*, (see the small figure below Figure 33).

p is a wedge-shaped piece which supports the slider *l* that carries *k*, the fulcrum of the lever *i*.

q is a fixed bar of the clock-frame, supporting the wedge *p* and the slider *l*, as well as other parts of the wheel-work.

The action of the regulating part of the clock-work is as follows. When the speed of the clock increases, the balls *bb* expand, and raise *e*, *f*, *h*, and *i*; and when the speed has reached to a certain amount, the curved part of the lever *i* is pressed upwards against the lower surface of the wheel *m*, and the retardation produced by this friction prevents the velocity from becoming greater. At this limiting speed, the balls revolve once in a second of time, very nearly. In order to increase the limiting speed, the wedge *p* must be pushed further inwards by means of the screw *o*; then the slider *l* and the fulcrum *k* will drop, and a greater expansion of the balls *b* (which implies a greater speed of rotation) will be necessary to make the lever *i* touch *m*. In order to diminish the limiting speed, *p* must be drawn towards *o*.

Professor Challis has found that the rate of the clock is altered in a very small degree by the want of balance of the telescope (which is sometimes considerable). I think it probable that the upward motion of the pressing part of *i* is made too small relatively to the expansion of the balls *b*, so that in the gradual approach of *i* to *m*, the increase of friction, from contact with oil and dirt, is rather too gradual: and that the clock would therefore be improved by an alteration of the levers which would carry the upper joint of *h* further from the fulcrum *g*. The movement of the clock is, however, extremely uniform.

r is a small bell; a hammer will be seen above it, which strikes the bell frequently when the clock-weight has nearly run down. The mechanism for this purpose (not exhibited in the drawings) is very simple: the cord *u*, when its unfolding coil approaches one end of the barrel, presses a lever sideways, which turns the catch of the small hammer into such a position, that some pins upon the wheel *Q* raise it, and cause it to strike the bell in its fall.

The following are portions of the going-fusee, Figure 34.

ss are the two clicks abutting on the lever-frame *C*, and lodging in the teeth of the internal ratchet *a*. The two clicks fall alternately into teeth of *a*.

t is the cord attached to *C*.

u is the other part of the same cord, which higher up is wrapped round the barrel.

v is the pulley, and *w* the weight. The weight at present upon the clock is 688 lbs, and it descends in one hour 3 feet 5 inches.

x is the point of a lever, turning on the fulcrum *y*; the stud at the end of *x* is immediately under the clicks *ss*; the other end of the lever is *d*, and this is pushed outwards by the spring *β*. In the ordinary going of the clock, the spring *β* presses the end *d* nearly to the point of the square spindle *F*, and the end *x* then raises the clicks *ss*, and thus prevents the disagreeable noise of the continually-repeated fall of the clicks, as the teeth of *a* pass under them. But when the winding-up-key is pressed upon the square spindle *F*, the fork *d* is driven to the position shewn in Figure 34, and *x* is brought so low that the clicks *ss* can fall into the ratchet, and can thus exercise their proper function in maintaining the going of the clock. The winding-up-key is large, with four winch-handles.

Figure 35, Plate X, is a small apparatus, attached by Professor Challis, for assisting the hour-angle-movement of the polar-axis, when it is in unusual need of assistance. This apparatus is fixed to the frame of the south steps, near to the box of the clock-work.

A is a weight.

B is a pulley under which the cord *C* passes. One end of *C* is carried by small pullies and rollers to be attached to the polar-axis at any convenient point *D*; the other end is wrapped round a small windlass *E* with ratchet and winch, by which the weight can be raised when it has dropped too far, without disturbing its action on *D*.

Figure 36, Plate XII, is a sketch of the support of the upper or north end of the polar-axis.

HH are the two north piers, built independently of the walls; they correspond to *E* and *F* in Figure 2. A small chamfering of their faces at the top, to prevent them from interfering with the arches that cut off the corners of the square room, is not represented in the figure.

II are the deals built into the piers, and having their edges carefully turned towards the center of motion of the telescope.

KKKKK is the cast-iron triangle with its two projections for attachment to the outside of the deals. All its various parts are turned edgeways towards the center of motion of the telescope.

LL are the wrought-iron braces. At the top they are connected with plates of iron which are bolted through the deals to the projections of *K*. At the bottom they are connected with plates of iron which are also bolted through the deals to opposite plates.

MM is one of what may be called the *roots* of the deals. As no memorandum of the form of these roots has been preserved, and as they are now perfectly concealed in the brick-work, it is possible that in describing them merely from memory, I may commit some trifling error. They are however nearly as follows. At the level of the floor there is laid a triangle, *M*, of stout iron plate, as large as can be placed in the plan of the pier. Firmly connected with this are two plates, *OO*, embracing the deal, and fastened to it by bolting through ; and two braces *N* connecting these plates with the front angles of *M*. Upon these irons the bricks and cement are laid in such a manner, that it is next to impossible that the deal should be disturbed in its position among them.

PPP is another triangle, at a place near the middle of the pier (in height). The angles of this are connected by braces *QQQ* with the plates *RR*, which embrace the deal and are bolted through. Upon these irons the upper parts of the brick-work are carefully laid.

The support of the northern end of the polar-axis is extremely firm. It is entirely free from the lateral tremor which I have witnessed in the upright iron support of a large equatoreal.

Figures 37 and 38, Plate X, represent the upper pivot of the polar-axis, and its immediate support.

K is the iron triangle.

L is the brass plate screwed upon *K*.

M is the *Y* in which the pivot *N* turns.

O is a collar pinned to *N*, to prevent the pivot from slipping out of the *Y* in any accidental disturbance.

P is a friction-wheel.

Q is one of two powerful springs by which it is pressed upwards.

Figure 39, Plate XIII, represents one of the principal poles or beams of the polar-frame.

A is the pole whose ends lodge in the cells *M* of the polygon, Figures 28, 29, 31.

BB are iron straps, two at each end, which are fixed to the pole by bolts *CC* passing through them.

DD are the ends of the iron straps cut into screws for nuts. These screws pass through the small holes by the side of *M*, Figure 28, and the nuts are applied below the iron polygon, so that the poles are firmly drawn into the cell.

The length of each pole is 21 feet 2 inches; its diameter at the thickest part 5½ inches. They are cut from Norway fir-poles. Before they were mounted, their external surfaces were repeatedly painted with linseed oil.

Figure 40, Plate XIII, represents one of the braces.

A is the brace, 3 inches square.

B is a cast-iron socket, with a projecting heel.

C is a strong bolt, 1 inch in diameter, tapped in the heel. The use of this bolt is, by being driven, virtually to lengthen the brace, or to exert a thrusting force at each of its ends. The bearing of the braces in the cells *N*, Figures 28, 29, and 31, is upon the points of the bolts *C*.

Figure 41, Plate XIII, represents one of the iron straps.

AA are the two portions of the strap. The iron is 1½ inch broad, and $\frac{3}{10}$ inch thick.

BB are the short bolts with nuts, by which the portions *A*, *A*, are drawn together, to shorten the strap.

These three parts (pole, brace, and iron strap) may be considered as the three elements of which the polar-frame is constructed. In order to understand the following description, the reader must conceive that the polar-frame consists of two framed pillars (one supporting each end of the declination-axis), and that each of these framed pillars consists of a framed triangular prism. The separation of the pillars will be well seen in Figures 2 and 13; and it will also be distinctly indicated by the directions of the cells *NN*, in Figure 28, which mark the planes of the braced sides. Each of the prisms has two external sides and one internal side; the two external sides are similar, but the internal side is different from them.

Figure 42, Plate XIII, represents one of the external sides of one of the prisms.

AA are poles, with their drawing-screws *B*.

CC are braces, with their sockets *D*, and thrusting bolts *E*.

FF are the portions of the iron strap, with its drawing bolts *G*.

L, *M*, *N*, have the same meaning as in Figures, 28, &c.

The braces *CC* have abutments in *AA*, and are driven firmly to these abutments by forcing the bolts *EE*, or by screwing the strap-bolts *G*.

Figure 43, Plate XIII, represents the internal side of one of the prisms. The arrangement of its parts differs from that of Figure 42 only in this respect, that it is necessary to have two straps *F*, instead of one, because the declination-axis passes through the middle of this side.

The reader who has made himself familiar with the principle of resistance to torsion, as laid down in the introduction, will perceive that each of the framed triangular prisms thus constructed is (when all its bolts are tight) able to resist torsion, and consequently that the polar-frame, consisting of the union of these two prisms by two similar polygons at their ends (one at the upper end, the other at the lower end), is able to resist torsion. It is also easy to see that, by proper management of the bolts, the form of the polar-frame may be very sensibly changed. Suppose, for instance, it were required to force outwards the middle part of the external pole of either prism. This would be accomplished by relaxing the straps that take hold of that middle part, and forcing the thrusting bolts of the braces which abut at the same part. Suppose it were required to change one of the sides from a rectangle to a rhomboid, or *vice versa*. All that is necessary is, to relax the thrusting bolts of two braces whose bolts lodge in cells at one angle of the rectangle, and to force the two brace-bolts which lodge at the other angle of the rectangle. It is supposed that all the bolts of the upper half of the braced sides are relaxed for any operation of this kind. After the completion of the operation for the lower half, all the bolts of the upper-half are to be tightened. When the polar-axis was first mounted, it was necessary to go through a series of adjustments of this kind, in order to give the proper position to the lower pivot, and the proper width for the reception of the declination-axis. After this the bolts were all forced tight.

I have only to add to this account of the polar-frame, that I believe from the report of Professor Challis, and from my own trials, that it entirely fulfils the intention of its construction, and that it is perfectly firm in the resistance to torsion, as well as in resistance to general flexure. And I conceive that the same principle may be advantageously adopted, with alteration of details, in the polar-frames of other equatoreals. In an instrument so large as this, I think the adoption of thrusting-pieces for the diagonals and drawing-straps for the sides of the rectangles is probably best. But in a smaller frame it might perhaps be found convenient to use thrusting-pieces for the sides of the rectangles, and drawing-pieces in great number (forming a lattice-work of hooping-iron or of laths) for the diagonals.

Figure 44, Plate XIV, represents the telescope-tube. It is constructed of wood.

A, *A* are the planks forming two sides of the telescope-tube. The tube is nearly 19 feet long; the planks are 1 inch thick near the middle of the length, and $\frac{1}{2}$ inch thick near each end. A section at the middle of the telescope is a square of $13\frac{1}{2}$ inches. The tube was made square in its whole length, and then the corners were chamfered off, and the holes thus formed were stopped up with triangular pieces of wood, so that the ends are regular octagons.

Upon each octagonal end a brass ring 3 inches broad is screwed, for the attachment of the optical parts.

B, B, B, B, are square stops within the tube, to which the four planks are screwed.

C, C, are the triangular pieces stopping up the holes which were made by chamfering the square tube so as to form octagonal ends.

D, D, are the brass rings at the ends.

Figure 45, Plate XIII, represents one half of the declination-axis. It is made of cast-iron. The two halves are precisely similar, and were cast from the same pattern.

A is the pivot, with a narrow mushroom-head. Its diameter is nearly $2\frac{3}{4}$ inches, and its length is nearly the same.

B, B, are plates of iron (in the same cast) for strengthening the connexion of the pivots with the center.

CC is the trough which embraces half the telescope-tube, the other half being embraced by the other half of the declination-axis. The length of this trough, or the extent through which it embraces the telescope, is 4 feet.

DD are edge bars (in the same cast) to strengthen the trough.

EE are holes in a flange, through which bolts pass to connect the two halves of the declination-axis.

Figure 46, Plate XIII, represents the bearing of one of the pivots of the declination-axis.

AA is a principal pole in the external angle of one of the framed prisms; it is one of those poles which in Figures 2 and 13 are seen to the extreme right and left, or of which in Figure 67 one is central and nearest to the eye; or one of those which, in Figure 28, occupy the cells *MM* which are farthest from the center.

B and *C* are two pieces of cast iron, shaped to embrace a pole which is nearly square. The pole is shaved to that form in the part where these irons embrace it. The only use of *B* is to give hold to the screws *DD*, which fix *C* in its place.

E is a piece projecting from *C*, in the same cast.

F is a plate of brass, screwed to *C* and *E* by four screws, *GG*. The bearing-piece which is represented in the figure is that which has an adjustment for making the declination-axis transverse to the polar-axis; for this, the holes in *F*, through which the screws *G* pass, are elongated in the direction parallel to the length of the pole. For the other bearing-piece the holes are round.

HH are antagonist screws which pass through a projection of *F*, for moving it up and down; the points of the screws rest on *E*. For the other bearing-piece these are wanting.

I is a projection from *F*, in the same cast with *F*, in which is the concave bearing for the pivot.

K is a cap which is screwed upon *I* by the screws *LL*.

The bearing of the pivot is in a concave cylinder, with some portions cut away. At that point of the concave cylinder which is nearest to the pole, a proper recess is made for receiving the mushroom-head of the pivot.

Figure 47, Plate XIV, represents the telescope as mounted in its declination-axis, and exhibiting a general view of several small parts which will hereafter be described in detail.

AA is the square telescope-tube.

BB the two halves of the declination-axis, screwed together so as to form an efficient declination-axis, securely holding the telescope. The extreme length of the declination-axis, from the end of one pivot to the end of the other, is 5 feet 8½ inches.

C is the object-glass-cell, to be described under Figures 56 and 57.

DDDD are small iron rods extending from the object-glass-cell to the eye-end, and confined at distances by small staples; these rods are to enable an observer at the eye-end to effect the adjustments of the object-glass, as will be seen in Figures 56 and 57.

E is the plate of brass, or breech-piece, closing the tube of the telescope, and bearing (as here represented) a micrometer eye-piece, with position-circle, and a chronometer. See Figure 55.

F is a brass bar, strengthened by an edge-bar, and turning on the pin *G*.

H is a declination-rod. Plans of the various declination-rods will be seen in Figures 49 to 54; details of their connexion with the bar *F* will be seen in Figure 48; and a general view of the position of one when in use will be seen in Figure 67.

I is the clamp, sliding on *H*, and taking hold of a pin fixed in the brass bar. See Figure 48.

K is the toothed-wheel-work, for moving the bar relatively to the telescope, or the telescope relatively to the bar.

L is the graduated arc at the end of the bar.

M is the microscope, carried by the telescope, for reading the graduations of the bar.

Figure 48, Plate XIV, represents on a larger scale that side of the telescope, near its eye-end, which bears the brass bar, &c.

AA is the wood-work of the telescope-tube, *B* the brass ring and breech-piece.

C is the brass bar passing under a bridge, *c*.

D its graduated limb. The available extent of this, as measured by the angular motion of the telescope, is 1° 22′.

E the micrometer-microscope, for subdividing the divisions of *D*.

F a rack-work, screwed to the telescope-tube.

G a milled head, acting on a train of wheels of which *H* is one, and of which the last pinion works in the rack-work *F*. This milled head and train of wheels are carried by the bar *C*. The wheel-work will be seen in greater detail in the small figure at the side.

I is a declination-rod, graduated to north-polar distance.

K is a slider upon it, which is secured by the clamp-screw *L*.

M is a piece connected with *K*, having at its end a fixed staple *N*, and a slider, *O*, of which the end has a deep notch (forming a *Y* to embrace the pin *Q*). In the ordinary state, this slider is forced to the pin *Q* by a strong spiral spring concealed within *M*; but for the convenience of putting the staple off and on the pin *Q*, a drawing screw *P* is provided, by which the slider *O* can be drawn back.

Q is the pin fixed in the brass bar. It has a mushroom-head, of which the external surface is conical, so that the staple *N* is easily passed over the conical head, and then lodges behind its shoulder; and when the spring is permitted to force up the slider *O*, the connexion of the staple *N* with the pin *Q* is perfectly firm.

To explain the use of this, it must be remarked that the lower end of the declination-rod is fixed to one of the poles of the polar-frame by a staple, sliding *Y*, and pin, exactly similar to these, and wanting only the slider upon the declination-rod with its clamp. The declination-rod in use assumes therefore the position seen in Figure 67. Its immediate effect then is to hold firm, not the telescope, but the pin *Q*. And the telescope may be moved relatively to this pin by turning the milled head *G*. This gives great facility for sweeping in declination to the extent of 1° 22′. And, as the relative movements of the brass bar and the telescope are measured by the graduations of *D*, there is given very great facility for measuring differences of declination to that amount. At the same time, the telescope is held in its position with extreme firmness.

Figures 49, 50, 51, 52, 53, Plate XV, represent the four declination-rods, (Figures 50 and 51 exhibiting different sides of the same rod), and Figure 54 represents two sliders with staples, &c., (such as are described in Figure 48, *K*, *L*, *M*, *N*, *O*), to be used under different circumstances. For understanding these, the reader is referred for a moment to Figure 67. It will there be seen that the declination-rod is attached to a pin on one of those principal poles, the bottom of which is nearest to the eye-end of the telescope, in Figure 67, and which may be called the northern pole. But there is also a similar pin on one of those poles whose bottom is farthest from the eye-end of the telescope, which may be called the southern pole. So long as the eye-end of the telescope is on the north side of the polar-frame, it is convenient to use as the point of attachment that pin which is on the northern pole; but when the eye-end of the telescope enters between the poles, it is necessary to use that pin which is on the southern pole; when it passes further still, the pin on the northern pole must be used; and when it passes far beyond the polar-frame for the observation of objects on the lower meridian, the pin on the southern pole is the more convenient. The rods are accommodated to these various circumstances.

Figure 49 represents the rod which is to be attached to the pin on the southern pole, and which may be used for objects between 10° below the celestial pole and 26° above it.

Figure 50 represents a rod to be attached to the pin on the northern pole, and which may be used for objects whose distance from the celestial pole is included between 26° above it and 58° above it.

Figure 52 represents a rod to be attached to the pin on the northern pole, and which may be used for objects whose distance from the celestial pole is included between 48° and 92°.

Figure 53 represents a similar rod, to be similarly applied for north-polar distances included between 92° and 126°.

In this manner we have provided for all polar distances included between − 10° and + 126°. To provide for still greater distances below the celestial pole, Figure 49 is graduated on the opposite side, so that if applied to the pin on the northern pole, and in the opposite direction, it can be used for polar distances between + 12° and − 26°; and Figure 50 is graduated on the opposite side, so that if applied to the pin on the southern pole, and in the opposite direction, it can be used for polar distances between − 26° and − 52°. This last graduation is represented in Figure 51.

The letters *AP* and *BP* (above pole and below pole) have relation to similar letters upon the clamps connecting the great equatoreal circle with the polygon, (see Figures 28 and 30). While the *AP* graduations are used, the vernier near the *AP* clamp will give the true right-ascension of the object. While the *BP* graduation is used, the vernier near the *AP* clamp will give the true right-ascension, increased or diminished by 12^{h}.

For these different graduations, different sliding staple-pieces must be used, as shewn in Figure 54. This is necessary because, in Figure 48, the clamp-screw *L* must be on the side furthest from the telescope-tube, and the staple-piece *M* must be on the side nearest to the eye-end.

It is evident that, by graduating both sides of each rod, the instrument could be used in either position for objects in every part of the meridian. The rods of Figures 49 and 50 are however the only ones which are yet graduated on both sides.

The diameter of the declination-rods in their graduated part is about 1·1 inch; in the parts of Figures 52 and 53 which are not graduated, the diameter is about 2 inches. As there is no slide-motion of the smaller tube within the larger, they are very stiff. The end of each takes a shoulder-bearing in the staple-piece which hangs on the pin in the pole, and is secured there by a screw. The rods, clamps,

&c., were constructed under my superintendance, but the graduations were arranged by Professor Challis.

Figure 55, Plate XVI, represents the eye-end of the telescope complete (with a wire-micrometer mounted on it), as viewed from the side opposite to that in Figure 48.

A is the wooden tube, and *B* the brass breech-piece.

C is the position-circle, *D* its slow-motion-screw and clamp, and *EE* are microscopes for reading its divisions.

F is the head of a pinion for adjustment to focal length, and *G* is the tube which is slid inwards and outwards by the action of *F*.

H is an eye-piece inserted in *G*, and held by friction only. All the eye-pieces of every kind are thus inserted in *G*.

I is a declination-rod.

K is the graduated arc of the brass bar, and *L* the micrometer-microscope for reading it. (See *D* and *E* in Figure 48).

M is the lamp for illuminating the field of view.

N is a circular plate, turning on a screw in its center, and having a hole in snail-shape for limiting the aperture through which the light of *M* enters the side of the telescope.

O is a milled head for turning a pinion whose teeth work in the teeth of the wheel *N*.

PPPP are the square ends of rods (represented by *D*, *D*, in Figure 47), by which the screws affecting the adjustments of the object-glass are turned. Small keys are provided, which fit upon these square ends; but as they are not often used, they are not usually mounted.

Q is a half-seconds chronometer, fixed by screws in a cell; its winding-up-key will be seen projecting from one side. By the use of this chronometer there is no necessity for the reference to a clock, which (with a telescope of such a length) would be very inconvenient; and therefore no clock is provided in the room.

R is the finder. It is a telescope of 28½ inches focal length, and 2¾ inches aperture.

Figures 56 and 57, Plate XV, represent the object-end of the telescope, with the apparatus for adjusting the object-glass. The same letters apply to these two figures.

To understand the object of these adjustments, it is necessary to consider what are the movements which may be required to make the performance of an object-glass the best possible. They appear to be the following: (1) It may be necessary to tilt the whole object-glass; (2) It may be necessary to turn one lens round, while the other remains fixed, in order to choose their best relative position; (3) It may be necessary to move one lens upon the face of the other, in order to center the lenses. The apparatus is adapted to these three purposes.

A is the wooden tube.

B the brass ring attached to it.

C is the object-glass-cell.

D, D, D, three cocks projecting from the object-glass-cell.

E, three corresponding cocks projecting from the brass rings.

F, screws, which work in *E* by ball-and-socket joint, and are tapped in *D*.

G, rods connected with *F* by universal joint, and led down the telescope-tube to the eye-end. They correspond to some of the rods *D,* in Figure 47, whose ends are represented by *P,* in Figure 55.

The object-glass-cell *C* is not fixed in the ring *B*, but is simply held by the three screws, *FFF*; and the observer at the eye-end of the telescope, by turning the proper rods *P,* (Figure 55), by means of a key, can, while he is observing a star, turn either of the screws *F,* and thus tilt the object-glass. The first of the adjustments above mentioned is therefore obtained.

H is the ring (concealed by the front plate of the cell) which holds the convex lens, or crown-glass-lens. It is cut in teeth on its external edge.

I is a toothed roller which works in it.

K is the axis of the roller *I*.

L is a rod connected with *K* by universal joint, and led down the telescope-tube to the eye-end; corresponding to one of the rods *D,* in Figure 47, whose ends are at *P,* in Figure 55.

The observer, therefore, by turning the proper rod at the eye-end, can turn the roller *I,* and can thus turn the crown-glass-lens, while the flint-lens is unmoved. The second adjustment is therefore obtained.

M is a frame carrying the axis of *I*.

N is the joint fixed to the cell *C,* on which *M* turns.

U, V, W, are a roller, frame, and joint, opposite to *I, M, N.*

i, m, n, u, v, w, are similar apparatus, in a diameter transverse to that in which are *I, M, N, U, V, W.* It is to be remarked, however, that the rollers *U, i,* and *u,* are smooth; the only roller which has teeth being *I*.

O is a bell-crank-lever, or rather lever-frame, which turns upon an axis, that is parallel to a tangent to the object-glass-cell, and is carried by that cell.

P is one of the pins forming the axis on which *O* turns. It is screwed into the cock *R*.

Q is a small projection from the lever *O,* pressing the roller-frame *M*. Thus by turning *O* upon its center *P,* the roller-frame *M* and the roller *I* are pressed towards the object-glass-cell, and force the crown-glass-cell *H* to slide upon the face of the flint-glass.

R is a cock projecting from the object-glass-cell.

S is a screw which works by a ball-and-socket in *R,* and is tapped into a ball which works in *O*.

T is a rod, connected with *S* by universal joint, and led down the telescope-tube to the eye-end; corresponding to one of the rods *D*, in Figure 47, whose ends are at *P*, in Figure 55.

U, *V*, *W*, are the opposite roller, roller-frame, and joint; and *X* is a strong spiral spring which presses the end of *V*, and thereby urges the roller *U* against the crown-glass-cell *H*, so as to keep it in firm contact with the roller *I*.

In like manner, *o* is a bell-crank-lever, turning on an axis of which *p* is one end, pressing the roller-frame *m* with its projection *q*; *r* is a cock in which turns the spindle *s*, that is tapped into *o*; *t* is a rod by which *s* is turned, and which is led to the eye-end; *x* is a spiral spring pressing the opposite lever-frame *v*, so as to keep *H* in firm contact with *i*. The observer therefore at the eye-end, by turning the proper rod, can turn the screw *S*, and can thereby force the crown-glass-cell in the direction from *I* to *U*; or, if he turns the rod in the opposite way, can permit the spring *X* to push the crown-glass-cell in the direction from *U* to *I*. And by turning another rod, he can turn the screw *s*, and can thus force the crown-glass-cell in the direction from *i* to *u*, or can permit it to be pushed by the spring *x* in the direction from *u* to *i*. Thus the third adjustment is obtained.

I may mention here that the artist, by departing from my instructions, has made this part of the apparatus a little more complicated than is necessary; as, in the form which I designed, one lever would have been sufficient instead of the two, *M* and *O*.

This power of adjustment by the observer is so convenient, that I would recommend that any large object-glass be fitted with it.

The clear aperture of the object-glass is a little more than 11½ inches. Its focal length, from the front of the convex lens to the place of the image, is 19 feet 5¾ inches. By means of the apparatus just described, Professor Challis has adjusted the object-glass to very admirable performance. I have seen the triple star ζ Cancri with great beauty, and am confident that the object-glass is competent to any observations of the closest double stars. I have also seen the large planets with great beauty.

The telescope is fitted with several eye-pieces of different kinds, which require no description. As one eye-piece, however, was arranged by me specially for this telescope, (though I have since used similar eye-pieces on a telescope at the Royal Observatory of Greenwich), I may perhaps with propriety describe it here.

Figure 58, Plate XVI, represents the longitudinal section of a double-image eye-piece, of four lenses. The focal lengths of the lenses, reckoning from the object-end to the eye-end, are in the proportion of 4, 4, 8, and 4; and the intervals between the lenses are 4, 14, and 9. These numbers make an achromatic eye-piece, according to the theory laid down by me in the *Cambridge Transactions*, Vol. III. Great care is taken to adjust the distance between the first and second lenses, so that the image of the object-glass falls exactly on the second lens. The second lens is divided, and one half is made to slide by the side of the other, by means of a micrometer-screw. The work of this part is represented in Figure 59. By the sliding of this half, the image formed by one half of the rays from the object-glass is made to move while the other image remains stationary. The use of this eye-piece, for measures, is exactly similar to that of the heliometer, or any other double-image telescope.

It is necessary, for the proper performance of this eye-piece, that the pencil of light be pretty accurately divided into equal parts by the line dividing the second lens. For then only can the images be equally bright. In order to insure this condition, the eye-piece ought to be carried by a plate transverse to its tube, which turns by motion on a line of hinges parallel to the line of division of the second lens, and can be adjusted with reference to that hinge-motion by a screw. This adjustment was not provided for the eye-pieces of the Northumberland Telescope, but I have lately adopted it with advantage at the Royal Observatory.

I may also state here an improvement (not yet decisively tried by me) which I have made in the principle of this eye-piece. The numbers above given constitute an eye-piece achromatic in the ordinary sense of the word; that is, the image receives no colour from being brought to any other part of the field than the center. But this applies to the fixed image only, and not to the moveable one, which when far separated is sensibly coloured. I have lately found, however, from theory, that it is possible to construct an eye-piece which shall be achromatic for both images; and the numbers which I am about to try are the following:

For the focal lengths; the focal length of the first (or that nearest to the object-glass) may be any whatever; those of the others are to be 5, 1, 1; these numbers being multiplied by any arbitrary unit. The divided lens is that whose focal length is 5.

For the distances between the lenses: the first distance (reckoning from that nearest to the object-glass) is to be equal to the focal length of the first lens; the others are to be 2 and 1·75; these numbers being multiplied by the same arbitrary unit as that for the focal lengths.

The power of the eye-piece would be changed by changing the first lens.

I have not yet published the details of this theory.

Figure 60, Plate XVII, contains a ground-plan of the observing-chair-frame. Figure 61 contains an elevation of its back; and Figure 62 is a longitudinal section. The scale is $\frac{1}{32}$. The great length of the telescope renders it necessary to provide special means for easily placing the observer in all positions in the surface of a sphere whose center is the center of the telescope; and this is done by making a frame, of which the upper edge is nearly a circular arc whose center is the center of the telescope, and causing this frame to traverse horizontally round a pin in the floor, exactly below the telescope center; then the observer's chair slides on the chair-frame. The same letters have the same application in Figures 60, 61, and 62.

A is the pin in the floor, under the center of the telescope. It is the same as *N*, in Figure 2.

BBBB are various beams of the chair-frame, parallel to the floor.

CC are two blocks at the smaller end of the frame, for giving the proper elevation at that part.

DD are the bars giving the first degree of slope upwards from the horizontal part.

EE are the bars giving the second degree of slope upwards.

FF are the bars giving the third degree of slope upwards.

GG are the back-pieces, which are not quite perpendicular to the floor.

H is a braced frame for supporting the middle of *EE*.

I is a braced frame, and *KK* are external braces, for maintaining the uprights *GG* in their proper position.

L is a ladder, attached to one side of the frame, to enable the observer to ascend to his chair.

MM are two small wheels which support the smaller end of the frame.

NN are two wheels, 18 inches in diameter, which support the larger end of the frame. One of these wheels has teeth in its inside.

O is a winch and sliding-rod by which the observer turns the wheel-work that acts on the interior teeth of the large wheel, and thus causes the chair frame to move on the floor.

P is a bar connecting the two uprights *GG*, and supporting the pulley *Q*. *P* is bent, to leave room for the iron *M* and the rope *N* of the chair (Figure 64) to pass.

R is a rope passing over the pulley *Q*, and supporting the chair.

S is a winch, with pinion-work and ratchet, for raising the chair through large elevations.

TTT, in Figure 62, is the groove within the side of the frame, in which the pins *BBBB* of the principal chair, Figure 64, and the pins *BBBB* of the lower chair, Figure 65, are compelled to slide.

Figure 63, Plate XVII, is a view of the machinery by which the observer, when seated in his chair, moves the chair-frame.

BB and *K* are horizontal beams and brace, as in Figures 60 and 61.

N is one of the large wheels, as in Figures 60 and 61.

O is the winch, as in Figures 60, 61, and 64.

T is an eye-bolt, as in Figure 64, turning in the chair, and allowing the long shaft from the winch *O* to pass through its eye. The shaft has a slider within it, compelled by means of a stud in a groove to turn with it; and thus the winch *O* is always in a convenient place for the observer, the shaft always adapting itself to the proper length.

U is a hook's joint at the end of the slider.

V is a bevelled pinion which it turns.

W is a bevelled wheel in which *V* works.

X is a pinion on the same axis with *W*.

Y is the row of teeth within *N*, in which *X* works.

Z is a latch, by lifting which the wheel *W* and pinion *X* can be withdrawn from action with the other wheels, and the chair-frame can then be pushed along the floor by hand.

Figure 64, Plate XVIII, is a view of the upper chair.

A, *A*, are its two principal bars.

B, *B*, *B*, *B*, are the four pins which slide in the groove *TTT*, in Figure 62.

C is the seat, and *D* the foot-stool.

E is the back of the chair, turning with hinges on the seat.

F is the rope which supports the chair; the same which passes over the pulley *Q*, in Figures 60 and 61.

G is a small windlass round which the end of *F* is wound, and to which it is fastened.

H is a ratchet-wheel fixed to *G*; *I* is a click.

K is a small lever, whose end slides with a fork under a mushroom-head of the axis of *H*; it carries a pin which lodges in the teeth of *H*.

By means of this lever and ratchet-wheel, the observer, when seated in the chair, can with great ease raise or lower the chair with himself on it, and can thus, while using the telescope, adjust himself exactly to the proper height.

L is a bend of the upper bar connecting *AA*, in the form of a common crank. This bar turns in the wooden bars *AA*.

M is a bent bar which turns upon the crank *L*. One end is fastened to the top of the chair-back, and the other is acted on by the cord *N*.

N is a cord fastened to this bent bar, and wrapped round the small windlass *P*.

Q is a ratchet-wheel connected with *P*. It has a click, &c., similar to that for *H*.

The observer when seated in his chair can, by turning the wheel *Q*, pull or relax the rope *N*, and can thus bring the chair-back *E* backwards or forwards. He can thus with ease place himself in a position in which his eye is at the proper distance from the telescope, while his head is properly supported by the back of the chair.

The mechanism of the bars *L* and *M*, though generally efficient, is not satisfactory to me. The arrangement which I wished to obtain was one which should give the required motion to the chair-back without any projection in front of the chair-back, or behind the bars *AA*. I could not, however, contrive anything quite satisfactory.

Figure 65, Plate XVIII, represents the lower chair, adapted for use on both sides of the zenith, for small zenith distances.

AA are the principal beams.

BBBB the pins sliding in the groove *TTT*, Figure 62.

CC are the two backs, turning on hinges, of which one is raised when the observer's head is to the north, and the other when his head is to the south.

DDDD are large wedges.

EE are dove-tails on which they slide.

FF are iron hooks of a square form, fastened to the backs *CC*, and underneath which the wedges *DD* slide. By drawing the wedges back to the ends of *A*, the backs *CC* will sink into the plane of *AA*; by thrusting the wedges forward, the backs may be raised considerably.

Figure 66, Plate XVIII, represents the chair used for observations very near to the celestial pole.

A is a board about 7 feet long, nearly filling up the space between the two prism-sides of the polar-frame.

B is an iron rod with a square hook at the end, for hooking under that side of the polygon, between the prism-sides, which is the higher, or the nearer to the south side.

C is a rod, jointed to *A* and *B*, which acts as a bridle to *B*.

D is a staple, with a pin, which can be fixed in one of several holes in *B*, and will thus place the upper end of the board *A* at different heights above the polygon.

E is a sliding bar at the other end of *A*, bridled by the rod *F*, and adjustible in the staple *G*. The bearing of the board upon the lower edge of the polygon is by the bar *F*; and thus the adjustment of *E* to different heights in *G* will place the lower end of the board *A* at different heights above the polygon.

H and *I* are seats or rests, which by means of pins lodging in holes can be fixed in different parts of *A*.

Some parts of this chair were arranged by Professor Challis.

Figure 67, Plate XIX, is a north-and-south section of the building and instrument, intended to give a general view of the principal parts of the mechanism of every kind in combination, the machinery of the shutters excepted. It exhibits the interior appearance of the octagonal walls, the interior appearance of the dome, the south steps, the clock-work box beneath them, the polar-frame with its supports at the upper and lower end (the adjustment at the lower end and the large equatoreal circle being lightly traced), the general structure of the polar-frame, the bearing-piece for the declination-axis, the telescope as mounted with its finder, the declination-rod and its attachment, the chair-frame and chairs; the observer in the upper chair holding in his hand the long handle to the hook's joint by which a slow motion in hour-angle is given to the polar-frame relatively to the equatoreal circle, and having at his command the long handles which communicate motion to the great wheel of the chair-frame, and to the machinery for turning the dome. The machinery for turning the dome is also shewn, and two of the holdfasts of the dome.

It will here be seen that all the movements which are necessary during the continuation of a series of observations, are completely under the control of the observer, without implying any necessity for his departing from his position in the observing-chair.

G. B. AIRY.

October 6, 1843.

Although very great labour was employed in the examination of the drawings and engravings, the following errors have been discovered since the impressions of the plates were taken.

Plate VI, Figure 17. *For* Hodfast *read* Holdfast.

Plate VII, Figure 21. There is an error in the neighbourhood of the letter *H*. The bar *I* ought to pass through the eye of the short bar projecting from the beam, and *not* the bar *H*, as is represented in the figure.

Plate IX, Figure 29. In two of the cells *NN*, short lines should be drawn to shew the internal re-entering angles of the cells.

Plate XII, Figure 36. In the left-hand pier, the bar *IRO* ought to be represented as passing *within* the triangle *P*, in the same manner as in the right-hand pier.