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DESCRIPTION

OF THE

TRANSIT CIRCLE

OF THE

ROYAL OBSERVATORY, GREENWICH.

ORIGINALLY PUBLISHED AS APPENDIX TO THE GREENWICH OBSERVATIONS, 1852.

20796.

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INTRODUCTION.

In the Report of the Astronomer Royal to the Board of Visitors of the Royal Observatory of Greenwich, dated 5th June, 1847, it was stated that meridional instruments carrying larger object-glasses were now required for the wants of the Royal Observatory. In an " Address to the individual members of the Board of Visitors of the Royal Observatory," by the Astronomer Royal, dated 1847, December 20th, a proposal for a large Transit-Circle was explained in considerable detail.

The Board of Visitors took this proposal into consideration at their extraordinary meeting of 1848, January 15th, and by formal resolution expressed their approval of it. This resolution was communicated to the Lords Commissioners of the Admiralty, and their Lordships were pleased immediately to give their sanction to the proposal, and to take the necessary steps for providing the requisite funds.

The object-glass was purchased of Mr. Simms (after trial and approval by me) in the spring of 1848, and at the same time a detailed model was prepared by me. This model was exhibited to the Board of Visitors at their meeting of 1848, June 3rd.

In the summer of 1848 Troughton's circle was removed to a temporary position on the external walls of the East Buildings, and the alterations necessary for reception of the new instrument were made in the circle-room and piers. The instrument was also commenced by Messrs. Ransomes and May, the engineers to whom the construction of the massive parts was intrusted; and, as early as the advance of the larger portions of the instrument permitted, Mr. Simms proceeded with the optical and graduated parts.

In the autumn of 1850 the instrument was mounted, and the requisite wooden stages, &c., were immediately prepared. Observations were commenced with it on the first observing day of the year 1851.

G. B. Airy.

Royal Observatory, Greenwich.
1853, December 14th.

In reprinting this Description, the original text has been preserved (with unimportant omissions), and additions have been made describing the alterations made in the instrument to the present time.

1868, January 22nd. G. B. Airy.

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DESCRIPTION OF THE TRANSIT-CIRCLE OF THE ROYAL OBSERVATORY, GREENWICH.

PLATE I. gives a perspective view of the Transit-Circle from the north-west, supposing the ladders removed, and the pillars which support the roof broken off.

On the right side is the western pier. Upon its external face are seen the eyepieces of seven microscopes, (one pointer-microscope, or microscope for reading the whole number of graduations, and six micrometer-microscopes,) and the attachments for four micrometers not mounted, (used occasionally for examining the graduation,) all carried by one solid brass plate. The inclined position of these eyepieces shows that the microscopes, whose tubes are merely perforations of the pier, are directed towards the circumference of the large graduated circle. The bent tube seen among the eyepieces is the gaspipe leading to the lamp whose flame is in the centre of the eyepieces ; the pipe is, for the most part, concealed in the pier. This portion of the pipe is jointed, in order that it may be turned away when observations are made on the collimator in the axis of the instrument. The smoke-chimney, for carrying off the hot air from the lamp, and for shading the eye, is omitted. At the north and south ends of the pier are the steps for descending into the observing pit. At the top of the pier are the standards carrying a large wheel, over which passes a chain ; which on one side sustains a pile of rectangular plates of lead operating as a large counterpoise, and on the other side is attached to the fulcrum of the ordinary transit-counterpoise, and to the large vertical rod (cut with a screw-thread) by which the transit-circle is lifted when necessary. Between the standards is seen the ordinary transit-counterpoise, (in shape resembling a hammer,) and on the left side of the large vertical rod is one of the slenderer rods that sustain the friction-wheel-frame, by which the ordinary counterpoise acts to support the transit axis.

[The engraving, and the preceding description, correspond to the state of the instrument for several years after its erection. The chains which carried the counterpoises were plate-chains, each link consisting of numerous parallel plates of brass pierced by a steel pin; the chains had been proved by trials with weights far exceeding any which they were required to carry. On 1863, November 16, the western chain broke ; the counterpoise was checked in its fall, and no important injury was done. Iron link-chains of the simplest construction were then substituted for the brass plate-chains, and new wheels were mounted, adapted to the chain-links. The space in which each counterpoise ascends and descends was inclosed with iron plates, and blocks were placed to receive the shock of the counterpoise, in the event of its falling.]

At a distance to the left is the eastern pier. In the form and dimension of its central mass, it corresponds to the western pier, but it has also north and south wing-walls (the north wing-wall is seen in this view) for carrying the extremities of a large iron arch whose middle part is on the lower part of the western face of the eastern pier, and for supporting the ends of two iron intersecting arches above. The intersecting arches are adapted to sustain the pressure and friction (and thus to prevent tremor) of the two inclined arms bearing large counterpoises, whose lower terminations carry the quicksilver trough; to the lower arch is clamped, in any required position, the middle of a horizontal bar connecting these inclined arms. The western face of the eastern pier also carries two projecting plates, of which one is seen here, for the clamps of the clamp-circle ; the rod of a hook's-joint depends from the clamp. The apparatus at the top of the eastern pier is generally similar to that on the top of the western pier ; the view shows distinctly the screw-cut large rod and the bevelled-wheel-nut, by whose rotation the large rod is raised.

Between the two piers, at mid-height, is the transit-circle, in the form of a transit-instrument, with conical tubes and cubical centre-piece, carrying on its eastern side a clamping-circle, and on its western side a graduated circle, whose graduations are viewed by the pier-microscopes ; and also a steering-wheel or circle furnished with handles, for turning the instrument. Several parts of this will be described in detail hereafter. Since the preparation of this drawing, the eye-finder, which is represented as carried on the end of the telescope, has been removed.

Between the bases of the two piers is the observing-pit, extending in the north and south direction, as far as the extreme faces of the pillars which support the roof, (whose bases only are exhibited in the drawing). There is in each end of the pit a moveable stage, whose top is level with the floor, and whose front next the centre of the pit has steps. Near to the base of the eastern pillar in the view is seen (imperfectly) the iron crane which carries the store of quicksilver, but which is usually turned out of the way into a recess cut in the face of the wing-wall. A new iron crane, generally similar to this, has lately been mounted near the south end of the pier, as a more convenient position.

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At the extreme left of the drawing is shown the pier carrying the north collimating-telescope. The axis of the telescope is at the same height as the axis of the transit-circle, and the object-glass is turned towards the transit-circle. The wooden box which covers the telescope is supposed to be removed. [It will be mentioned below that a larger collimating-telescope is now substituted.]

In the upper and left-hand portion of the drawing is seen the machinery for opening the roof-shutters. The roof-opening is along the ridge of the roof; it is covered by four shutters, opening on hinges upon the eastern side; the drawing shows two of these closed and one open. The interstice between two adjacent shutters is covered by a supplementary flap, which is raised by either of the neighbouring shutters; one of these flaps is partially seen in the drawing as raised by the raised shutter. The machinery for opening and closing the raised shutter is shown. At a convenient height above the floor there is fixed to the wall a frame carrying a winch, on whose axis is a pinion driving a toothed-wheel, and upon the axis of this toothed-wheel is a pinion acting in a rack which forces a rod up or down. The upper end of this rod is connected with a bridle-rod, whose centre of motion is at the top of the wall; and from the point of connexion a rod leads to the extremity of a short lever-arm, which is carried by a horizontal spindle that turns in bearings fixed to the lower side of one of the ridge-beams. Near each extremity of this spindle is fixed a long crooked bar, of which one end acts (by a jointed connecting-rod) to support the shutter, and the other end carries a counterpoise. Upon the toothed wheel frame is a bell; in the movement of the winch either for opening or for closing the shutter, when the movement is *nearly* completed, a hammer strikes the bell, as a warning to the person who turns the winch that he must move it gently. A large iron forked hook, whose centre of motion is on the wall, is so placed that, either when the shutter is closed or when it is fully opened, the hook will lodge upon the winch-handle, and will thus effectually secure the shutter in its position.

PLATE II. is a view of the Transit-Circle from the south-east, the ladders being removed, and the roof-pillars being broken off.

On the right side is the eastern pier. The wing-walls and the intersecting iron arches are seen in reverse, and the triangular frames which support them are seen. The machinery at the top of the pier is also seen. Between the standards that carry the large wheels and the chain, there is a horizontal bar, above the ordinary counterpoise-lever, from which two slender rods pass down into the pier (these are also seen on the western pier, and less perfectly on the piers in Plate I.): these rods are for the purpose of lifting the cap which covers the transit-pivot. The plate which projects from the eastern pier towards the instrument and carries the clamp is seen partly behind the pillar that supports the intersecting arches; the hook's-joint spindle bears a bevelled-wheel, which works in another bevelled-wheel that drives a screw which pinches the rim of the clamping circle.

To the left is the western pier. Upon the top is seen the same machinery as upon the eastern pier (now somewhat altered, as described for Plate I.); but there is also a smooth vertical hand-wheel for slightly turning a spindle connected with the wheelwork that drives the bevelled-wheel-nut (see the eastern pier in Plate I.), by which the screw-cut large rod for lifting the transit-circle is drawn up. At the centre of the vertical-wheel there is jointed-on a crank-rod; which at present is lifted to a nearly vertical position, in order to leave the space between the piers free from obstruction. When the instrument is to be raised, the upper end of the crank-rod is brought down to the eastern pier, and is locked into the corresponding spindle of the machinery on the eastern pier; and then, by applying the hand to the crank and turning it, both pivots of the transit-circle are raised simultaneously and by equal degrees. Opposite to the graduated circle of the transit-circle are seen the tubes carrying the object-glasses of the microscopes. There are short tubes fixed to the pier, having external flange-ends, upon which are fixed other short tubes by means of broad-headed screws in large holes, allowing of adjustment, both radially and circumferentially; and in these tubes slide the object-glass-tubes, which thus can be adjusted to focus. Of the eleven microscopes, five are seen in this view. P is the pointer-microscope, or microscope for reading the whole number of divisions; B and D are ordinary reading microscopes, 60° apart; β and b are microscopes distant respectively 20° and 25° from B, used only in the examination of the graduation. Corresponding to every microscope there is, at a small distance, radially nearer to the centre, a hole through the pier; this hole is to permit the light of the central lamp (shown on the outside of the western pier in Plate I.) to fall upon those divisions which are viewed by the microscope. Immediately below microscope P, a bracket carries a small setting-pointer, which is directed to a rough graduation on the side of the graduated circle furthest from the pier. At mid-height of the pier is an inclined channel, cut in the face and end of the pier. In this channel are two galvanic wires; their higher extremities communicate with two springs (seen partly behind the graduated circle), by which connexion is made with a contact-piece on the eye-end, for use in the American or chronographic method of transits (as will be hereafter described); and their continuation downwards leads under the floor, and to the recording apparatus in the Chronograph Room.

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Between the piers, at mid-height, is the transit-circle. The object-glass of the telescope is turned towards the spectator. Beyond the telescope are seen, first, the steering-wheel, or wheel for turning the transit-circle, with numerous handles inserted in its circumference; secondly, the graduated circle, whose surface (for a reason to be hereafter explained) is conical. Upon the internal conical surface is the delicate graduation which is viewed by the micrometer-microscopes; upon the exterior conical surface is the rough graduation to which the setting pointer applies.

Between the piers, at the bottom, is the quicksilver-apparatus. Close to the wing-wall is one of the inclined rods; of which the upper ends are seen in Plate I., bearing large counterpoise-weights, and rubbing against the intersecting arches. From this inclined rod there projects a spindle; a similar spindle projecting from the other inclined rod; which spindles carry a horizontal frame. Upon an advanced north-and-south spindle of this frame there turn a pair of levers, whose advanced points carry a pair of pivots in the line of the advanced upper edge of the quicksilver-trough, and whose points next to the pier carry a large cylinder of lead as counterpoise; and upon a lower north-and-south spindle of the frame, near the face of the east pier (not seen in this view), there turn another pair of levers, of the same length as the former, carrying a lower pair of pivots attached to the bottom of the quicksilver-trough. [Since this drawing was prepared, a trifling alteration has been made in the mounting of the quicksilver-trough: all the movements here described are preserved, and there is also given a means of tilting the trough endways.]

Beyond the quicksilver-trough is seen the south moveable stage, its steps being seen in reverse; and at its base are partially seen two of the rollers by which it travels across the pit. Beyond the moveable stage is seen a small portion of the steps for descending into the pit. At the extreme left of the drawing is seen the south collimator. The telescope, and the solid forks on which it is mounted, are precisely similar to those of the north collimator; the form of the pier is slightly different, preserving its full breadth to the end next the transit-circle, in order to leave room for a niche in which the transit-clock is placed.

PLATE III. gives a ground plan of the Transit-Circle-Room and original Reflex-Zenith-Tube-Room; and view of the transit-circle, &c., as seen from above.

A is the entrance-door from the Front Court.

B, the entrance from the Astronomer Royal's official room.

C, the entrance from the Computing Room (by an intermediate passage).

D, the entrance from the Eastern Rooms.

(E, the entrance to the Reflex-Zenith-Tube-Room.

F, the ascent to the Reflex-Zenith-Tube.

G, the elevated platform of the Reflex-Zenith-Tube-Room.

H, the Reflex-Zenith-Tube.)

[The letters E, F, G, H, correspond to the position of the Reflex Zenith Tube at the time of erection of the Transit Circle. The Reflex Zenith Tube has subsequently been erected in a room of nearly the same dimensions in the external re-entering angle south-west of C.]

I, I, I, I, windows.

J, the south wall-shutter, all its parts being supposed to be closed.

K, an iron attached to the large upper division of the wall-shutter at one-third of its height.

L, a horizontal arm of a vertical shaft, which turns in bearings upon the wall, at the same height as K.

M, an iron connecting-rod, connecting the extremities of L and K.

N, a lever-handle, at a convenient height for the hand, by which the vertical shaft is turned, and with it the arm L, which moves the wall-shutter, by the action of the connecting-rod M upon the iron K.

O, a hook fixed to the wall for retaining the lever N in the position which keeps the shutter closed.

P, a hook which retains the lever N in the position proper for keeping the shutter open.

(The letters K, L, M, N, O, P, apply both to the north and to the south shutters.)

Q, the upper portion of the north wall-shutter open; this part opens outwards.

R, the middle portion of the north wall-shutter open; it opens inwards.

S, the lowest portion of the north wall-shutter open; it opens outwards by horizontal hinges, falling downwards. (The southern wall-shutter is similar in its divisions and movements to the northern.)

T, T, T, T, the four frames of toothed-wheel-work for opening the four shutters on the ridge of the roof.

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U, U, U, U, hooks or forks which prevent the winches of the shutter-machinery from moving, whether the shutters be open or closed.

V, an opening through the wall into the Astronomer Royal's official room, for planting a telescope to view the collimator in the axis of the transit-circle ; it is usually closed by a small door in each room.

W, W, W, W, four pillars which support the roof, near to the two ridge-beams.

X, the western pier, built entirely of stone.

Y, the eastern pier, entirely of stcne.

Y′, Y′, the wing-walls of the eastern pier, of stone.

Z, Z, Z, Z, portions of the observing-pit at its corners, which alone are visible in this view ; all other parts being concealed by the ladders on the transit-circle, and by the instrument itself, and by the moveable stage.

a, a, the descents into the pit, passing under the ladders.

b, b, b, b, b, b, the western ladders for ascending to the stage above the graduated circle.

c, the horizontal stage above the graduated circle. It is divided by a longitudinal line of hinges, in order to permit a part to be lifted so as to leave a clear space for the rise of the graduated circle when the transit-circle is lifted. Three of the highest steps of the ladders on each side are also divided, so that portions of them can be removed.

d, d, the eastern ladders rising to the stage above the clamping-circle. These ladders are imperfect at the bottom ; there is no access to them from the floor of the room ; they are used only for supporting one foot of the observer when he has ascended by means of the western ladders.

e, e, e, e, e, e, e, e, wooden frames fixed to the floor, with iron rods passing over the wing-walls of the eastern pier, for supporting the ladders d, d, without touching the pier or wing-walls. (This method of support is necessary, because the ladders d, d, do not touch the floor ; it is not required for b, b, which rest on the floor.)

f, the eastern stage above the clamping-circle. It is divided by a longitudinal line of hinges, to allow a part to be raised for permitting the ascent of the clamping-circle when the transit-circle is lifted. Portions of the three highest steps of the ladders are also removeable.

g, g, g, g, iron triangles which support the intersecting arches and their pillars.

h, h, the two large counterpoises of the quicksilver apparatus. The rods which carry h, h, pass between the eastern pier and the eastern stage and ladders. (It will be remarked that the quicksilver-apparatus here is not in the same position as in Plates I. and II.)

i, the central cube of the transit-circle (not entirely seen). The line of flanges along the middle, united by bolts and nuts, is the line dividing the two iron castings of which the axis is formed, every part from that line to the extremity of the eastern pivot being in one cast, and every part from that line to the extremity of the western pivot being in another cast. [It will be mentioned hereafter, in the description of Plate XV., that a considerable part of the face i, on each side of the cube, has lately been removed, in order to permit passage of rays of light between the north and south collimators ; proper coverings being provided, for exclusion of dust when the thorough vision is not required.]

j, the eye-tube of the telescope, which, as far as the shoulder at which the smaller eye-tube commences, is one cast of iron.

k, the object tube, which, as far as the flange on which the object-glass-cell is fixed, is one cast of iron.

l, l, l, l, the pedestals of the standards of the large grooved-wheels which support the chains that carry the large counterpoise-apparatus.

m, m, the large counterpoises. [In this plate, and in all which follow, the iron cases which inclose the counterpoises in their descent are omitted.]

n, a gas-light with its smoke-chimney, fixed to W, for illuminating the face of the transit-clock.

o, o, smoke-chimneys from two gas-lamps under the angles of the ladders b, b, for illuminating the observing-pit. (The gas-lamps are not seen in this view.)

p, a gas-lamp with its smoke-chimney, at the top of the western pier, for illuminating the eyepiece of the transit-circle when the reflecting-apparatus is used for observation of the nadir-point.

q, the gas-lamp at the centre of the microscope-eyepieces, with its smoke-chimney, into which all the other smoke-chimneys are led, and which passes through the roof of the room.

r, a block of wood, 11 inches high, upon which the observer steps to read the two highest of the micrometer-microscopes.

s, s, the two moveable stages in the pit ; their steps are imperfectly seen below the two ends of the telescope. The observer

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stands upon these stages to view the collimators ; and sometimes sits on the steps to observe moderately low objects. When the quicksilver-trough is brought into the middle of the breadth of the pit, the stage is pushed on its rollers to the western side. It cannot be pushed to the eastern side.

t, the pier for the south collimator ; it is of brick, covered with a slab of Yorkshire sandstone.

u, (dotted lines,) the recess in the brickwork of t, below the stone-slab, in which the transit-clock is placed.

v, a small projection from the clock case, in which a chronometer is placed when it is to be compared with the transit-clock [now removed].

w, the pier for the north collimator.

x, x, the wooden boxes which cover the collimators.

y, y, hinged portions of the boxes, which are turned up to expose the eye-ends of the collimators ; when the collimators are viewed by the transit-circle ; or when one collimator views the other (the transit-circle being previously raised).

z, z, gas-lights which throw light upon the reflectors carried by the eyepieces of the collimators ; by which reflectors the light is directed through the tubes of the collimators.

[In consequence of the substitution of larger collimating telescopes, alterations have been made in some parts of this apparatus. The object-ends project somewhat more towards the middle of the room, and the eye-ends touch the third or lowest wall-shutters of the north and south openings. Those shutters are perforated, and external reflectors are mounted in them, for reflecting the light of the sky into the collimators.]

a, *a*, extremities of the long handles attached to the hook's-joints of the clamps, here shown as limbered to the feet of the ladders d, d.

PLATE IV. gives a Plan of the Roofs of the Transit-Circle-Room and original Zenith-Tube-Room.

b, *b*, are the two roof-shutters next the middle of the room.

c, *c*, the two roof-shutters next the north and south ends of the room. These shutters carry those parts of the external pediment-mouldings and ornaments which are nearest to the apex of the pediment.

d, *d*, *d*, *d*, the lines at which the pediment-mouldings are cut through to admit of the movement of the apex. When *c* is raised, all between *d* and *d* is raised with it.

e, *e*, *e*, the supplementary shutters, covering the chinks between the large roof-shutters.

f, *f*, portions of the ridge-beams, and of their lead flashings not covered by the shutters.

g, *g*, lead gutters under parapets.

h, a single flap-shutter for the zenith-tube.

PLATE V. gives a Transversal Section of the Transit-Circle-Room, principally for showing the movement of the Roof-Shutters, but showing also the relation of the Piers and Observing-Pit, with a part of the Lifting-Mechanism, and with a Telescope in position for viewing the Axis Collimator.

i, the long rod by which the toothed-wheel acts upon the end of the bridle.

k, a joint in the rod, immediately above the rack ; which is necessary, in order to permit the small lateral motion of the top of the rod without strain to the rack.

l, the bridle-iron.

m, the rod connecting the junction of *i* and *l* with *n*.

n, the short arm of the three-rayed shutter-lever.

o, the long arm of the same lever which carries the counterpoise.

p, the long bent arm of the same lever which lifts the shutter.

q, the short connecting-rod by which *p* raises the shutter. (The lower diagram represents the shutter as closed, and the upper represents it as open.)

r, the crank-arm used for connecting the lifting-machinery on the two piers, jointed to the spindle of one of the wheels on the western pier, but at present turned aside to leave the space between the piers free from obstruction.

s, the hinge at which *r* is jointed upon the spindle of the western pier.

t, the end of the spindle of the eastern pier; pierced with a hole for a large pin, to which the forked end of *r* will be attached by a pin when *r* is lowered.

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u, u, the points to which are attached the ends of the chains, whose opposite ends support m, m. These points are the upper extremities of the large screw-cut rods of the lifting frame; they are also the fulcra of the levers of the ordinary counterpoises.

v, v, the tops of the rods by which the covering-caps of the transit pivots are lifted.

w, w, the large vertical grooves in the piers, in which are the large screw-cut lifting rods for raising the instrument, the rods of the ordinary-counterpoise-frame, and the rods for lifting the cap from the pivot (omitted in this section of the piers).

x, x, the large holes through the piers, permitting communication of any kind from the outside of the piers to the ends of the transit-pivots. The bearing piece or "Y" of the transit-pivot rests on the bottom of *x*.

y, a 7-foot telescope, as placed in position for looking into the collimator of the transit-circle-axis. It rests upon two forks, which are planted (when occasion requires), one in the hole V in the wall, the other in the hole *x* of the western pier. The collimator-mark is a very minute hole in the small tube which projects from the eastern pivot of the transit-circle; it is illuminated by a small lamp placed in the hole *x* of the eastern pier. The eyepiece of the 7-foot telescope has a micrometer with position-circle, which can be placed so as to measure the ordinate of the image of the minute hole, either in a horizontal or in a vertical or in any other direction.

The telescope of the transit-circle (the two circles being omitted) is represented in the state in which it is used for observing the nadir-point. For this purpose, a trough of mercury below the floor of the observing pit was at first employed: latterly the ordinary mercury-apparatus (Plate IX.) is used. A long eyepiece, with an inclined glass reflector between its lowest lens and the wires of the telescope, is inserted in the eyepiece-socket. The hole in the side of the eyepiece, which admits the light that falls upon the glass reflector, and illuminates the field of view for this operation, is at the same height as the flame of the gas-lamp p.

In this plate is seen a portion of the upper part of one of the posts, W, with the short transversal block upon it, by means of which W supports a principal rafter and one of the ridge-beams.

PLATE VI. gives a Longitudinal Section of the Transit-Circle-Room, showing also the inner face of the Eastern Pier, the Transit-Telescope in two positions, and the two Collimators, but no other parts of the Telescope-Machinery.

Upon the collimator-piers, t and w, are seen the south and north collimators. The transit-telescope, in the position shown by j, k, is directed to the north collimator, and the wires of the north collimator are distinctly visible in it; and in like manner, if its object glass is turned to the south, the wires of the south collimator are visible in it. But when, by the lifting machinery, the transit telescope is raised to the position j', k', there is no interruption to the view of one collimator by the other, and the wires of either collimator may be seen in the eyepiece of the other. [It has already been mentioned that the object ends of the new larger collimating telescopes project into the room beyond the edges of the piers, and that their eye-ends touch the shutter S in its closed position].

z, z, are the vertical shafts turning in bearings on the end-walls, to which are attached the handles N, by which the shafts are turned, and the arms L, which, acting on the connecting-rods M and the shutter-irons K, open and close the shutters.

A portion of the lower or horizontal moulding and ornaments of the pediment is carried by the shutter Q.

The wall shutters are divided each into three parts, for the following reasons:—It is desirable that the principal part of the shutter should open outwards; because it is more convenient for the interior of the room; because it causes less disturbance in the external architectural arrangements; and because it keeps out the rain more completely. But it was necessary that its lower edge should not come so low as the bottom of the wall-slit, in order to avoid interruption of the paths on the outside of the buildings. The middle division was then made to open inwards, in order that it might close to the upper division with a rabbetted edge. But this division could not extend downwards to the bottom of the wall-slit, because it would, in opening, have come in contact with the eyepiece of the collimator. It was necessary, therefore, to provide a third division; and this, for the sake of a rabbetted edge, was made to open outwards, and, for avoiding interruption of the path, it was made to flap downwards. [That lowest shutter S is now firmly fixed to the wooden pannel below it; and that wooden pannel is attached by hinges to the side of the opening, so that the whole pannel with S can be opened outwards, to give facility for applying the eye to the eyepiece of the collimator].

PLATE VII. gives an Elevation of the Western Face of the Western Pier, in its ordinary state.

γ is the large wheel over which passes the chain, which at one end sustains the large counterpoise m, and at the other end supports the large screw-cut rod for lifting the transit-circle and the fulcrum of the ordinary counterpoise.

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is the end of the ordinary counterpoise.

is the cross-head carrying the rods which, by a friction-wheel-frame, support part of the weight of the transit-circle. δ and ϵ are at opposite ends of a lever.

ζ is the toothed-wheel-work for raising the transit-circle. By the crank-arm *r*, in Plates V., X., and XIII., the pinion seen to the right in this view is turned; this pinion drives the larger wheel in the centre of the view, and a bevelled-wheel upon the axis of the larger wheel drives the bevelled-wheel-nut (partially seen in this view) which turns in the screw-thread of the large rod for lifting the transit-circle.

The toothed-wheel-apparatus upon the eastern pier is similar, except in the following respect. On both lifting-rods the screw is right-handed. If the toothed-wheel-mechanism were similar, then when the machinery on the two sides is put in connexion, as shown in Plate XIII., one end of the transit-axis would be raised and the other end would be depressed at the same time. On the eastern pier, therefore, the pinion corresponding to that shewn in this view is carried so far out as not to touch the central wheel; and a wheel is interposed, acting both in the pinion and in the central wheel, which reverses the motion of the central wheel.

η is the large brass plate (interrupted in the upper part to leave room for the lamp-chimney) screwed to plugs in the pier and carrying the eye-ends of the eleven microscopes. The solid sockets of the eyepieces, and the pieces against which the micrometer screws take the bearing that determines their zero, are in the same cast of metal.

P, the pointer microscope, is used for registering the whole number of degrees and divisions of five minutes; and for that purpose it has a lower magnifying power than the other microscopes, and has only a single fixed wire in the field of view. Its solid socket, however, is furnished wlth a bearing piece for a micrometer-screw, and its object-end is fitted to receive a different object-glass; which are sometimes used for examining the graduation of the circle.

A, C, E, B, D, F, are the ordinary reading-microscopes, 60° apart, each furnished with a micrometer which makes a cross of wires pass over the image of a 5′ space in somewhat less than 5 turns; the micrometer-heads are divided each into 100 parts.

a and b are sockets of microscopes, distant 20° from A and B. Their micrometers, which are in every respect similar to those of A, B, C, &c., are removed when they are not required for examining the graduation. These microscopes give the means of ascertaining the error of every 20° of graduation.

α and β are sockets of similar microscopes, distant 25° from A and B. They give the means of ascertaining the error of every 5° of graduation.

θ is the frame of the "Y" supporting the pivot of the transit-circle, partially seen in the large hole *x*.

κ is a very large and deeply curved lens, supported by two slender brass standards. In describing the reflector which illuminates the field of view of the transit-telescope, it will be shown that it is necessary that the light of the lamp q be spread to the circumference of the reflector. But if the light of q enter immediately into the perforation of the axis, it cannot, on account of the smallness of the perforation, spread so much as is necessary. The large lens causes the diverging pencil of light from the lamp q to converge into the perforation, and then to diverge so as to illuminate the whole surface of the reflector. When the 7-foot telescope is mounted, as is shown in *y*, Plate V., for looking into the axis-collimator, the lens κ is removed, the lower division of the lamp-chimney q is slid upwards, and the lamp q is turned upwards by a joint in the gas-pipe.

λ is a key, now suspended on hooks, by the application of which the spring-piece that exerts end-pressure against the axis of the transit-circle is withdrawn.

PLATE VIII. gives a View of the Inner or Eastern Face of the Western Pier.

The letters A, C, E, B, D, F, a, b, α, β, indicate the object-glasses of the micrometer-microscopes, whose eyepieces are indicated by the same letters in Plate VII. Within them, radially, are the holes (one hole corresponding to each microscope) through which the light from the lamp q falls upon the divisions of the graduated circle which are viewed by the microscopes. The screw-cut lifting-rod is shown in the large groove *w*, but the lifting-stirrup is not shown; the rods which sustain the friction-wheel-frame are partly shewn, but not the friction-wheel-frame. The rods which lift the cap of the pivot, and the cap itself, are shewn completely.

μ is the cistern of the lubricator, for keeping the pivots constantly oiled.

ν are two springs, fixed to the pier by the intermediation of a galvanic insulator, and communicating at their fixed ends with the galvanic wires which pass to the recording-barrel (in the American or chronographic system of transits). Their free ends touch the two insulated brass rings upon the axis of the instrument, from which wires are led to the contact-apparatus at the eyepiece.

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ξ is a simple pointer, which is directed to the rough internal graduation of the circle. It indicates very approximately the north-polar-distance of the object observed with the telescope. A small reflector attached to it throws the light of the northern lamp o upon the graduation.

π is another pointer which indicates (nearly) the zenith-distance-south. It is used only to supply the degrees of the accurate or external graduation of the circle viewed by microscope P, when it happens that no numerated degree is seen in that microscope. (The reading of P is a few minutes less than the south zenith distance.)

ρ is the observing chair, 15 inches broad, used for zenith distances about as far as 45°. Either end of the chair can be lifted, for the support of the observer's back.

σ is a rod fixed to the pier, by grasping which the observer seated upon the chair ρ can move the chair and his own person.

At the bottom of each stage s are partially seen the wheels or rollers by which it may be removed transversally in the pit ; and also the long spindle-rod connecting a pair of rollers, one at each end of the stage, to insure that the stage in moving preserves its parallelism.

PLATE IX. gives a view of the Inner or Western Face of the Eastern Pier.

τ is the stirrup by which the lifting-apparatus raises the transit-circle out of its "Y"s. It is immediately attached to the large screw-cut rod.

υ is the friction-wheel-frame supported by the long rods which are attached to the cross-head ϵ, and therefore drawn upwards by the weight of the ordinary counterpoise δ.

ϕ, ϕ are two centre pins fixed in the pier, on which turn the long bars that carry the quicksilver-trough.

χ, χ are pins in the two long bars, which rub upon the intersecting-arches.

ψ is a large arch fixed to the pier ; the section of that part which projects from the pier is **T** shaped.

ω, ω is a bar connecting the two long bars near their lower ends, by pins on the faces of the bars.

(a) is a slider upon the arch ψ, taking a cramp-hold of the **T** section. Upon the face of this slider is a projecting-screw passing through the bar ω, ω ; on it turns a large nut with milled head, pressing the bar ω, ω. The bar ω, ω is slightly arched, its centre being further from the pier than its ends, and thus it acts partly as a spring. By turning the large milled head, the long bars are pressed firmly against the large arch ψ, and motion and tremor are effectually prevented.

(b), (b) is a bar carried in the same manner as ω, ω, and therefore necessarily parallel to the horizon. To this bar is attached the transversal-parallel-motion for the quicksilver-trough, which will be described hereafter.

(c) is the quicksilver-trough. It is represented here as covered by its wooden cover.

(d) is the tap for discharging the quicksilver from the trough ; its construction is represented in the enlarged section below. A detached conical plug is driven by the power of a screw into a conical seat. This construction has lasted perfectly tight, until after frequently passing through it the whole of the quicksilver carrying its superficial dirt, some gritty particles have been lodged in the hollow cone. A new construction has lately been adopted, in which, a frame being substituted for the trough (c), a somewhat smaller trough is made to turn (when necessary) upon horizontal transversal pins in that frame, so that the south end of the trough can be raised, and the quicksilver can be poured out from the north end ; this construction requires no tap.

(e) is the iron crane carrying the cistern of quicksilver ; its horizontal plan is represented in the enlarged sketch below. When the cistern is not in use for receiving or discharging quicksilver, it is pushed towards the east into a hole in the pier provided to receive it.

(f) is the tap by which quicksilver is discharged from the cistern. In its conical plug, conical seat, and driving screw, it is similar to (d) ; the quicksilver entering at holes in the side of the tap-cylinder. As the quicksilver ought never to be run completely out of the cistern of (e), no grit ought to pass this tap, and therefore it is in no danger.

(c)′ represents the position to which (c) is brought when the quicksilver of the trough is to be emptied into the cistern.

(c)″ represents the position of (c) when it is supplied from the cistern.

For adaptation to the new trough mentioned above, a new cistern-crane is provided at the south end of the pier ; its northern extremity projects 24 inches north of the south edge of the south wing wall Y′.

PLATE X. gives a view of the two piers from the South, and a section of the observing pit.

(g) and (h) are the two centres of motion which carry the quicksilver-trough. The two long rods of the quicksilver apparatus have near their ends, at (b), (b), (see Plate IX.), two long horizontal pins projecting towards the west ; and

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upon these pins are sockets of the same length connected by the bar (b), (b), Plate IX. At the west end of each socket is a centre of motion (g), and on a vertical projection from the eastern part of each is a centre of motion (h). The rods which turn on these centres of motion are of equal lengths, and are connected with pins fixed to the quicksilver trough (or more lately, with pins fixed to the frame that immediately carries the quicksilver-trough), whose differences of position on the trough in respect of horizontality and verticality are exactly the same as the corresponding differences of position of (g) and (h). This construction insures that the position of the quicksilver-trough, in its east and west movements, will always be parallel to itself.

(c)′ represents the trough as brought to the centre of the pit, in the state in which it is used for observing stars by reflexion.

(c)″ represents the trough as carried close to the eastern pier, either for the reception or discharge of quicksilver, or as placed aside when not in use.

(i) is a large leaden counterpoise, in the form of a cylinder, with a portion cut away in order to pass the bar (b), (b). It is carried by the short end of the rods which turn on the centres (g).

In this view will be seen the projection from the frame of the stage s, which prevents it from being moved into close contact with the eastern pier.

PLATE XI. gives a Horizontal Section of the Piers at the height of the centre of the Instrument; with a Vertical View of the Instrument as carrying its Circles; the Circles being shown in Section.

[See the notes regarding i in the description of Plates III. and XV.]

(k), (k) are the slightly-flexible brass plates fixed to the east pier which carry the clamps. It will be remarked that these plates are so long that the clamps are further from the pier than the limb which they grasp; this construction allows them more easily to be slipped off, for the purpose of raising the transit-circle.

(l), (l), is the clamping-circle shown in section. This circle is of cast-iron; the system of spokes (to be more fully shown hereafter) is in one cast, and the ring or circumference is in another cast. This principle of formation was adopted as tending to make the iron-castings sound and free from strain. The touching surfaces were turned and fitted together, and bolted together by short bolts and nuts. The bolts may be seen in the section, near the extremities of the spokes.

(m), (m), are perforations through the western pier, permitting the light of the lamp q to fall upon those parts of the limb (t) of the graduated circle (s) which are viewed by the reading-microscopes called A and B (see Plates VII. and VIII.) There are similar illuminating-perforations for all the other microscopes.

(n), (n), are convex lenses in these perforations, condensing the light of the lamp q on the points which are to be illuminated.

(o), (o), perforations which form the tubes of the microscopes A and B.

(p), (p), the mountings of the object-glasses of the microscopes, consisting of the following parts. The first part, which is nearest to the pier, is solidly fixed to the pier in the usual way, having for that purpose a flange parallel to the face of the pier, which is screwed to blocks lodged in the pier. This part has also at its exterior end, a flange whose plane is transversal to the axis of the microscope. The second part is a short tube with a flange, which is screwed to the exterior flange of the first part by screws passing through holes large enough to admit of some motion of one flange upon the other, and thus permitting a movement for adjustment either in the radial direction or in the circumferential direction. The third part is a short tube, carrying the achromatic object-glass, sliding in the second part and fixed in any required position by screws, and thus admitting of focal adjustment. There are similar perforations and arrangements for all the microscopes.

(q), (q), the eye-ends of the microscopes, which are all carried by the large brass plate η; the part against which the micrometer-screws rest being in the same cast with η, and all other parts being attached to η. The wires carried by the micrometer are in the form of a very acute X. The interval of threads of the micrometer screw is 0·04 inch.

(r), (r), convex lenses in the tubes, required by the following accidental necessity. When the microscopes were mounted, it was found that rather more than five turns of the micrometer-screw were required to carry the cross-wires of the micrometer over the space of 5′ included between the images of two successive lines upon the circle's limb. This would have required, in the reduction of every observation, a subtractive "correction for runs"; a very great inconvenience where so many numbers have to be combined by addition. In order to diminish the space between the images, without alteration of the micrometer screw, the lenses (r), (r), were introduced; and the "correction for runs" is now always additive.

B 2

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(s), (s), is the graduated circle, of cast-iron, of which the spokes and the ring are cast in two separate casts, in the same manner as those of the clamping-circle.

(t), (t), is the limb, of conical or dished form, in which are inserted two bands of silver carrying the graduations, one within the cone or on the side next the pier, the other on the outside of the cone. The band of silver within the cone carries the line-graduations to every 5′ which are viewed by the microscopes (o), (o), &c. The surface upon which they are cut is so inclined that a normal to it bisects the angle formed by the axes of the perforations (m) and (o). The light, which passes from q through (m) and falls upon the silver band, is therefore reflected by the laws of specular reflection through the microscope (o) to the eye, and thus the surface of the band is seen brilliantly illuminated, and the dark lines of the graduation are seen with remarkable distinctness. This principle of illumination appears well worthy of attention in the construction of every graduated instrument. The band of silver on the outside of the cone carries the rough graduation also to every 5′, used with the setting pointer ξ (Plate VIII.) and with π (Plates VIII. and XI.)

(u), (u), is the wheel with wooden handles, by which the instrument is turned.

(v) is a broad conical collar of iron with projecting edge fixed upon the western cone of the instrument. This projecting edge has clips which carry

(w), two narrow brass rings which are galvanically insulated by pieces of gutta-percha at the points of support. These two rings are touched respectively by the two springs ν, ν, which are fixed to insulated supports in the western pier, and thence communicate by wires with the recording apparatus proper for the American or chronographic method of transits.

(x) and (y) are wires soldered respectively to the two rings, which enter into holes in the cone of the axis, pass through the interior of the tube j, and are finally brought to the contact-apparatus on the eyepiece.

(z), (z), are the two cylindrical pivots. These pivots are in the same cast of metal as the cones to which they are attached, but they are not cast under the same circumstances. The mould for the cones was made of sand, but the mould for the pivots was made of iron, heated to a proper degree. This process (technically known by the term "chilling") gives a hardness to the surface of the cast-iron not much inferior to that of hardened-steel. The facility of combining hard metal for the pivots with soft metal for the cones, &c., in the same cast, was one of the circumstances which led me to adopt cast-iron as the metal for this instrument. The pivots were shaped and polished by grinding with emery. It is to be remarked that the flat pieces in the form of truncated flat cones, seen at the extremities of the pivots, are not portions of the pivots, but bearing-pieces, which prevent the pivots from having end-shake; that at the end of the cast pivot being fixed on the "Y," and that at the end of the west pivot being pressed by spiral springs, whose support is carried by the "Y." It is also to be remaked that the interior ends of the cylindrical surfaces of the pivots terminate with a distinct shoulder; this form was adopted in order to allow the polishing tool to pass completely over the cylinder, without which the cylindrical form could not have been assured through the whole extent.

On that portion of the conical axis which is nearest to (z) will be seen the rings defining the bearing-bands, on which the counterpoise-friction-wheels and the lifting-stirrup exert their pressures.

(*a*) is the place in which a lamp is set for examination of the form of the pivots.

(*b*) is the small tube carrying the collimator-mark, which, on occasions of examining the form of the pivots, is fixed in the end of the eastern pivot (z), passing through a hole in the truncated flat cone or end-stop without touching it; and which is illuminated by the lamp (*a*). When (*a*) and (*b*) are mounted for use, κ and q are removed, and the 7-foot telescope is placed in position as shown in Plate V.

The small semi-circular hollow at the middle of the east side of the east pier was made in the stones of the pier for the mounting of an ancient instrument; and is, in reference to the transit circle, entirely accidental.

PLATE XII. is an East-and-West Vertical Section through the middle of the Piers, principally for the purpose of shewing the Lifting-Machinery.

[See the note regarding i in the descriptions of Plates III. and XV.]

(*c*), (*c*), are the large screw-cut rods which support the lifting stirrups τ, τ. On the side of each of these rods is a longitudinal furrow passing through all the threads of the screw; this furrow corresponds to a fixed pin in the foundation plate l; and in the raising of the rod the furrow slides along that pin, and prevents the rod from turning.

(*d*), (*d*), are the bevelled-wheel-nuts which are driven by the wheelwork ζ, and which work in the threads of (*c*), (*c*), and thus raise the stirrups τ, τ

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(*e*), (*e*), are the rods, two on each side, which connect the friction-wheel-frame υ with the cross-head ϵ. Each is divided in the middle of its length, and a concave screw-piece takes hold of both parts of the rod, one by a right-handed screw, and the other by a left-handed screw ; and thus the rods are conveniently adjusted in length.

(*f*,) (*f*), are the solid iron-foundation-plates, strongly cemented in the pier, on which the "Y"s θ, θ, rest. The "Y"s were adjusted in position by the following process. First, (*f*) and (*f*) were adjusted as nearly as could be done by the use of a rod carrying a spirit-level. The "Y"s were planted on them, and the instrument placed in the "Y"s. The true line of collimation was found by the use of the collimators ; the wires were viewed by reflection, and the error of level was ascertained. Then the "Y"s were strapped upon the pivots, the instrument carrying its "Y"s was raised, and the surface of one of the plates (*f*) was scraped by a process well known to engineers ; then the instrument and its "Y"s were lowered, the new error of level was ascertained, and the process of scraping was repeated. When the axis was as nearly as possible horizontal, the pole-star was observed with the telescope, and its error of azimuth was ascertained ; by reference to one of the collimators, means were obtained of registering the azimuthal motion of the instrument ; and then, by the blows of a mallet upon a wooden lever, the instrument, with its "Y"s, was turned in azimuth till its position was sensibly correct. Then the screw-holes were cut in (*f*) for the screws which unite θ to (*f*), and the screws were driven tight, and in that state the "Y"s were left, and they have not since that time been moved.

The internal break of the surface of the stone to the west of *w* in the western pier is accidental. The external hollow cut in the same stone is for the reception of the lower sliding-part of the chimney of the central lamp.

PLATE XIII. gives a View on the tops of the Piers, with the machinery connected as for raising the Transit-Circle, and with the stages opened so as to admit of the raising.

No explanation of special parts is required for this plate. It will be seen that those portions of the upper platforms, which are next to the centre of the opening between the piers, are turned back upon their hinges towards the piers ; and that portions of several steps on each side (north and south), both of the east and west stages, are removed ; and thus a clear space is left for raising the clamping-circle on one side, and the graduated circle and hand-turning-circle on the other side, through a height sufficient for allowing the south-collimator to view the north collimator, and *vice versâ*, (see Plate VI.)

The crank-rod *r* is shown as connecting the wheelwork on the two piers.

PLATE XIV. contains details of the construction of the Transit Circle.

Figure (1) is a section of the transit-telescope and its conical axes. The letters have the same signification as in the preceding descriptions. Corresponding to (x) and (y) are seen the two galvanic wires which are soldered to the two rings (w), and pass thence through the interior of the instrument to the touch-piece on the eye-end, which will be shewn hereafter. The strengthening-ribs in the interior of the central cube i, are shewn here only so far as they are cut by this section ; they will be shewn more completely hereafter.

1, 1, are the strengthening rings in the same cast of metal as the object-end of the telescope. 2, 2, those in the same cast as the eye-end. 3, 3, &c., those in the same cast as the two halves of the axis. 4, 4, 4, 4, the diagonal braces of the central cube. 5, 5, the annular reflector, in the position in which it reflects the light of the lamp q, (after it has passed through the large lens κ, Plates XI. and XII., and has entered through the lenses 15,) and throws the light down the eye-tube to illuminate fully the field of view ; two of the prisms carried by the annular reflector are shewn at 5 and 5, but the prisms in the axis of the reflector, and the stop-arc, are omitted. 6, 6, the annular reflector, in the position in which it reflects no light to the field of view. At 6, 6, are two prisms ; and at 7 are two prisms in the axis of the reflector (one above this section and one below it) which, in this position only of the annular reflector, reflect definite beams of light in a definite direction down the eye-tube. 8, the stop-arc which defines the position of the annular reflector for this prism-reflection. 9, 9, &c., holes in 4, 2, 2, &c., through which the light from the prisms passes to the eye-end. 10, 10, prisms at the eye-end which reflect the light coming from the prisms 6, 6, obliquely upon the wires of the field of view. 11, a rod jointed to the annular reflector, and passing through the large flat piece or breech-piece at the end of the iron eye-tube, where it is within reach of the observer's hand.

The graduation of light in the field of view is therefore effected in the following manner. When the annular reflector is in the position 5, 5, it is in the position most favourable for reflection, and the field of view is then most brilliantly illuminated. By pushing the rod 11, the reflector is brought into a state less favourable for reflection, and the illumination of the field is diminished. On

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continuing to push the rod 11, the reflector is brought nearly to the position 6, 6, and the field is perfectly dark. On pushing still further, the reflector is brought exactly to the position 6, 6, and the light, which falls upon the prisms 6, 6, 7, 7, is then reflected by the prisms through the holes 9, 9, 9, 9, to the prisms 10, 10, and by them it is thrown upon the wires in the field of view, which are thus seen illuminated upon a black field. [The apparatus for graduating the light upon the wires will be described under Plate XVI., figure (26).]

12, 13, 14, are parts of the apparatus for forming an image in the *y* axis-collimator, to be viewed by the telescope in Plate V. 12 is a lens for condensing the light of a lamp on 13 ; 13 is a plate of pearl, in the centre of which is a small plate of brass with a hole $\frac{1}{100}$ inch in diameter ; 14 is a lens which produces an image of the hole $\frac{1}{1000}$ inch in diameter ; and this image is in the focus of the object glass 15. The rays of light which diverge from the image of the hole 13 upon the object glass 15 therefore emerge from it in a parallel pencil, and are fit to be received by the object glass of *y*, Plate V.

16 is the object glass, 8·1 inches in clear diameter.

Figures (2), (3), (4), relate to the object glass and its mounting. 1 is the ring which confines the object glass in its cell; 2, the screws which fix 1 ; 3, 3, two springs which press the edges of the lenses of the object glass ; 4, the bolts and nuts which connect the brass cell of the object-glass with the iron tube of the telescope ; 5, 5, &c., are adjusting screws which are tapped in the brass cell and press with their points the end of the iron tube.

Figure (5) is a view of the eyepiece. The galvanic wires (x) and (y) are seen emerging from the large plate and connected with brass pieces or " terminals " which are insulated by blocks of varnished wood. 1 is a brass spring connected by the terminal with the wire (x) ; 2, is a brass ring touched by 1 ; it is insulated from the ring 4, which carries it, by a ring of gutta-percha between them ; 3 is a brass spring connected by the terminal with the wire (y) ; 4 is a broad brass ring insulated by gutta-percha from the eyepiece tube which carries it, and touched by the spring 3 ; 5 is a metallic spring attached to 2, with a point which can be thrust (by a touch of its ivory button) through a hole of 2, to make galvanic contact with 3. The system of rings 2 and 4 can be turned round, still in contact with the springs 1 and 3, so that the touch-button of 5 may be in the position most convenient to the observer's hand.

It will be seen that by the pressure of 5 a galvanic contact is made between the two rings 2 and 4, and therefore between the wires (x) and (y), and therefore between the two rings (w), and therefore between the two springs ν, ν, Plate VIII., which touch them, and consequently between the wires that lead from ν, ν, to the recording instrument.

6 is the end of the rod which in Fig. 1 is called 11, and by which the illumination of the field of view is graduated ; 7 is a strong clamp on the fixed tube of the eyepiece for griping firmly the sliding tube of the eyepiece, (there are projecting studs on the fixed tube, and on the sliding tube connected by screws, for gentle movement of the sliding tube ;) 8 is the head of the declination micrometer ; 9 is a spindle carrying a pinion, which is turned by a contrate wheel on the lower side of 8, and carrying also an endless screw ; 10, a graduated circle moved by the endless screw of 8, and bearing on its edge figures which indicate the number of revolutions of the micrometer head 8 ; 11 is a glass box which incloses the transit-micrometer (whose arrangements are precisely the same as those of 8, 9, 10, but which is used much less frequently) ; 12 is the screw for sliding the eyepiece-plate from right to left across the field of view ; 13 is the eyepiece. A screw for moving the adjuster of illumination of wires is omitted.

Figure (6) is a longitudinal section of the eyepiece-tube ; 1 is the prism-plate ; it carries the prisms 2, 2, (called 10, 10, in Figure 1,) that illuminate the wires ; and it also protects the micrometer from the heat of the sun's rays ; 3 is the head of the transit-micrometer ; 4 is the eyepiece. The perforated plate above the prism-plate, for graduating the illumination of wires, is omitted.

Figure (7) is a view of the end of the eyetube ; 1 is the head of the declination-micrometer ; 2 is its counter of revolutions ; 3, the head of the transit-micrometer ; 4, its counter of revolutions ; 5, the screw which slides the large eyepiece-plate from right to left,—the *appui* of the screw is in a bent piece of brass or cock fixed to the eye-piece tube (seen better in figure (5)), and the internal screw which receives it is cut in the sliding plate ; 6, the large eyepiece-plate covering the whole end of the tube, which is moved by 5 ; 7, the screw which slides the smaller eyepiece-plate up and down,—the *appui* of this screw is in a brass stirrup attached to the plate 6, and the internal screw which receives it is cut in the smaller sliding-plate ; 8 is the smaller sliding-plate ; 9, the eyepiece which is carried by 8 ; 10, the case which encloses 3 and 4.

Figure 8 is an east-and-west section of the solid-iron-plate upon which each " Y " is planted. It is sunk in the stone to the dotted line. The thinnest part of the iron, which in this diagram is the left-hand edge, is next to the inner face of the pier.

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PLATE XV. contains details of the Transit-Telescope, Y's, Clamps, and Collimators.

Figure (9) is a section of the central cube of the telescope, in the plane passing through the telescope and the axes, to show its internal braces. The shaded parts show the extent of the braces in the central section ; the simple lines show the extent of the braces above and below this section. 1, 1, 1, 1, are the two longitudinal braces, one in each half cube ; 2, 2, the transverse braces ; 3, 3, 3, 3, the diagonal braces.

Figure (10) is a view of the inside of one half-cube supposing the other half-cube removed from it. 1, 1, are the longitudinal braces, fully seen ; 2, 2, the transversal braces, seen edgewise ; 3, 3, the diagonal braces, seen obliquely.

[This may be a proper place for describing the perforation made in the faces i of the central cube, (Plates III., V., XI., XII., XIII.). It is shown in Plate VI. that, by raising the transit circle, one of the collimators can be seen from the other ; but it appeared desirable to possess this power of vision without the trouble of raising the instrument. And it was found that, when a circle of 7 inches diameter was described on the face i, the amount of corresponding space in the interior of the cube, unincumbered by the braces represented in Figure (9), would be sufficient for the passage of light from one collimator to the other, provided that their object-glasses had 7 inches diameter. Accordingly, new collimators with 7-inch object glasses of the highest quality having been provided by Mr. Simms, the plate i on each side of the cube was perforated with eight sectorial apertures corresponding to the spaces between the braces in Figure (9). When the telescope of the transit-circle is placed in a vertical position, one collimator can be viewed from the other through these openings. Coverings of the openings on the two sides are provided, which can be opened by rods leading nearly to the eye-end of the telescope.

The tubes of the new collimators are constructed of cast-iron.]

Figure (11) is a view of the annular reflector, as seen from the eye-end, and figure (12) is an edgewise view of it ; 1, 1, are the pivots on which it turns ; 2, the point at which the long rod 11 of figure (1) is jointed to it ; 3, 3, 3, in figure (11), are the holes through which three of the prisms reflect the light to the prisms in the eyepiece tube, and in figure (12) are the prisms themselves ; 4 is the fourth prism ; 5 is the stop-arc, whose end touches one of the diagonal braces of the cube when the reflector is in the position proper for directing the light reflected from its prisms to the prisms of the eyepiece-tube.

Figures (13) to (19) relate to the " Y's," and the same references apply to all. Figure (13) is a view, from the space between the piers, of either the eastern or the western " Y " ; figures (14), (15), (16), are horizontal plan, side view, and external view, of the western " Y " ; and figures (17), (18), (19), are horizontal plan, side-view, and external view, of the eastern " Y." 1 is so much of the solid foundation-plate represented in figure (8) as is above the surface of the stone ; 2 is the front-plate of the "Y" ; 3 is the back-plate, and 4 is the lower-plate ; these, with the " Y " properly so called, are in one cast of metal ; 5, 5, are the nuts by which 4 is firmly screwed to 1, no power of adjustment being left ; 6, 6, &c., are nuts by which the end-plate is screwed to the back-plate ; 7 is the end-plate of the eastern pivot (the bar which crosses it being in the same cast) ; this plate is immoveably fixed, and the end of the eastern pivot is forced into contact with it, and thus the position of the transit-circle in respect of east and west motion is defined ; 8 is a hole in its centre, through which the tube (*b*) of figure (1) is passed, without touching the sides of the hole 8, for insertion in the end of the eastern pivot ; 9 is a cap with which the hole 8 is usually covered ; 10 is the end plate of the western " Y " not immoveably fixed ; 11 is a cylinder cast with 10 ; 12 is a larger cylinder, fixed by means of the screws 6, 6, in the interior of which 11 slides ; 13, 13, are strong steel springs, pressing the end-plate 10, and thus forcing the transit-circle eastward until the end of its eastern pivot touches the end plate 7. One end of the cylinder 11, namely that which is farthest from 10, is cut with a screw-thread ; and 14 is a circular nut, which works in that screw-thread ; it is turned by means of the key λ, represented in Plate VII.

When the transit-circle is to be raised from its bearings, the points of the key λ are inserted in the small notches of the nut 14, and the nut is turned forwards ; the cylinder 11 is thus drawn into 12, and 10 is withdrawn from the end of the western pivot, and the instrument can be raised without inconvenience. When the instrument is lowered, the nut is turned backwards, and the springs 13 force 10 against the end of the pivot.

The Y's are ground to fit accurately to the pivots through an arc of 15° on each side. The centres of these fitting portions are about 123° apart.

Figures (20), (21), (22), are views of the southern clamp, (the northern clamp is exactly similar, with the proper change of position only). Figure (20) is a view from the south ; figure (21), a view from the west ; and figure (22) a view from above. (k) is the broad thin plate which is screwed to plugs in the eastern pier and carries the clamp at its end. 1, 1, are elongated

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holes or slits, permitting the clamp to be slid so far as to be entirely disengaged from the clamping-circle when the instrument is to be raised; 2 is the bevelled-wheel, carried by the spindle to which the rod is attached by hook's-joint; this spindle has square ends below and above, admitting of the application of the hook's-joint to either place ; 3 is the vertical-bevelled-wheel in which 2 works, and which is connected with the clamp-screw; 4 is the biting lip of the clamp, which is drawn by the screw of 3 ; 5, is the limb of the clamping-circle. It will be seen that here is no provision whatever for slow motion ; and this was omitted by design; as it appeared very improbable that a slow-motion-screw could act successfully on a mass of matter so great as that of this transit-circle. When an object is observed in declination, the telescope is placed as nearly as possible in the proper direction, and the clamp is pinched tight; then the observation is completed by means of the declination-micrometer in the field of view of the telescope.

Figure (23) is a side view of one of the original collimators, intended to show the method of illuminating the wires when they were to be viewed by the other collimator or by the transit-telescope. The limited length of the room did not permit the illuminating light to be placed in the axis of the telescope, and the arrangement represented here was made for directing the light by means of a reflector. 1 is the place of the gaslight on the further side of the pier; 2 is a cylinder fitting on the eyepiece socket (the eyepiece being removed), and carrying two slender rods or standards; 3 is a parallelogram-frame, turning on pins in the standards of 2; 4 is a rod soldered to 3, by means of which 3 may be inclined or tilted ; 5 is a mirror which turns on pins in the frame 3 at right angles to the former pins ; 6 is a rod soldered to the back of the mirror, by which the mirror can be inclined or tilted in the frame 3. The mirror thus moves in jimbals. 7, 7, are two long wires, which are led from the ends of 4 and 6 nearly to the object-glass. The observer therefore stations himself at the object-glass and pulls or pushes the two long wires until he finds that the light of the lamp is distributed over the whole surface of the object-glass; it is then in a state fit for distinct vision of the wires.

The collimator in use was covered by a wooden box, of which a small part only is opened to expose the object-glass, and a part to expose the eyepiece. Plates of tinned iron were placed near the eye end, to protect the eye end and its support from the heat of the lamp.

[With the new collimators, this apparatus is not employed. The eyepieces are so close to the wall-shutters that the light of the sky can be conveniently reflected to them from external porcelain reflectors through holes in the shutters. Lamps are provided for direct illumination from the outside ; but hitherto they have not been used.]

Figure (24) is a view of the eye-end of the south collimator, showing the rack-and-pinion-slider for the eyepiece, and the head of the micrometer which slides the wires of the south collimator right and left. The micrometer head, when not in use, is inclosed in a glass box. The eye-end of the north collimator is nearly similar ; the eyepiece slides up and down in the same way, but the micrometer-head is at the lower side, so as to give an up-and-down movement to its system of wires. [With the new collimators the functions of the north and south collimators are reversed, and the corresponding change is to be made in this description.]

Figure (25) is a view of the object-end of the collimator; it requires no particular explanation.

PLATE XVI. contains details of the Wire-Plates of the Telescope and Collimators, the Nadir-Eyepiece, and the Circles.

Figure (26) shows the prism-plate of the transit-telescope as seen from the eye-end. The prisms to the right and left illuminate the vertical wires, and those above and below illuminate the horizontal wire. It is remarkable that the right and left prisms do not throw the slightest sensible illumination on the horizontal wire, and the prisms above and below do not in any degree illuminate the vertical wires.

[For understanding the principle of the apparatus by which the brilliancy of illumination of the wires is adjusted, it is to be remarked that the object desired was, to alter the effective breadth of each of the prisms, without altering its effective length. A moveable brass plate is therefore provided, nearly as large as the prism-plate, and sliding upon that side of the prism-plate which is next the object-glass. It is made to slide (by an external screw of high pitch), in a direction which makes an angle of 45° with the position of the prisms. It has a central hole, elongated in the direction of sliding ; and it has four rectangular holes corresponding to the prisms; the breadth of the holes being the same as the breadth of the prisms, but the length of the holes being greater than the length of the prisms. When the plate is in the position furthest from the external screw-head, its holes correspond in breadth with the prisms, and overshoot them in length in the directions furthest from the screw-head. The illumination then is maximum. On turning the screw, the breadth of the prisms is gradually cut off (the outside edges of the distant prisms and the inside edges of the near prisms being hidden), but no part of the length is cut off; till finally the prisms are

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completely covered and there is no illumination; in this state the holes overshoot the prisms in length in the directions nearest to the screw-head.]

Figure (27) shows the micrometers of the transit-telescope, as seen from the object-end. The two micrometers are perfectly independent. The transit-micrometer carries the whole system of transit-wires.

Figure (28) is the system of wires in the south collimator, as seen in its own eyepiece.

The dotted line represents the horizontal line. It will be remarked that the nearly-horizontal wires are not absolutely horizontal, but inclined about 3° to the horizon, and that the nearly-vertical wires are inclined about 3° to the vertical. It will also be remarked that one of the nearly-vertical wires is strong and the other is fine, and that the two upper nearly-horizontal wires are strong and the lower one is fine. The reasons for these constructions will be understood on inspection of the combinations.

Figure (29) represents the system of wires in the north collimator as viewed in the eyepiece of the south collimator, or as viewed in the eye-piece of the transit-telescope.

Figure (30) represents the combination of the two systems of wires, when the transit-circle is raised, and the wires of both collimators are seen in the eyepiece of the south collimator. The wires are here shown in the position corresponding to exact adjustment of the collimators. The two strong upper wires (nearly horizontal) of the south collimator serve only to define a small portion of the nearly-vertical fine wire of the south collimator, whose middle point is to be used in horizontal measures and horizontal adjustments. In like manner, the two strong upper wires of the north collimator define the small portion of the nearly-vertical fine wire of the north collimator whose middle point is to be used. Therefore, when horizontal adjustments of the two collimators are to be made, care must be taken that, by the vertical screw of the north [now of the south] collimator, the intersection of the nearly-vertical fine wire of the north [now south] collimator with each of its upper wires, be brought as nearly as possible to the same height as the similar intersections in the south [now north] collimator; and then the adjustment in the horizontal direction of the defined points of the nearly-vertical fine wires, can be effected very delicately by the horizontal screw of the south [now of the north] collimator.

The nearly-vertical strong wire of each collimator is used, in conjunction with its parallel fine wire, only to define that small part of the lower nearly-horizontal fine wire, whose middle point is to be used for vertical reference. Therefore, when vertical adjustment is required, the horizontal screw of the south [now of the north] collimator must first be used (if necessary) to bring the intersections of the fine nearly-horizontal wire with the two nearly vertical wires, in one collimator, to the same vertical as those of the other collimator; and then the vertical adjustment is effected by the vertical screw of the north [now of the south] collimator.

Figure (31) shows the appearance of the wires of the north collimator as viewed with the transit-telescope; the vertical and horizontal wires of the transit-telescope being adjusted upon the nearly-vertical and nearly-horizontal wires of the north collimator, and the points of reference of the collimator wires being the same as those spoken of in describing figure (30). The distance of the nearly-horizontal fine wire in the collimator from the strong wires is determined so that the referring point of the nearly-vertical fine wire and the referring point of the nearly-horizontal fine wire shall be in the same vertical.

Figure (32) is a section of the nadir-eyepiece. The reflector is of plane glass. Its inclination can be altered by a milled head on the outside of the tube, which is furnished with a clamp. Additional plane glasses can be placed in the ring of the reflector, if thought necessary.

Figure (33) is a plan and section of the clamping circle.

Figure (34) is a plan and section of the graduated circle.

Figure (35) is a plan and section of the circle for turning the instrument by hand.

Although reference has been occasionally made to the materials of which the different parts are composed, it may be proper to state that:

The "Y"s are made of cast iron, the surfaces on which the pivots rest being chilled.

The halves of the axis (each half including in one cast the half-cube, the cone, and the pivot) are of cast iron, the surfaces of the pivots being chilled.

The two large tubes of the telescope (object-tube and eye-tube) are of cast-iron.

The object-glass-cell is of brass.

The eyepiece-tube, &c., including the large flat plate or breech-piece on the iron eye tube, is of brass.

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The three circles are of iron. The two narrow bands in the graduation-circle, on which the divisions are cut (the accurate division and the setting division), are of silver.

The microscopic mountings, mountings of the internal collimator, nadir-eyepiece, and optical parts generally, are of brass. The external collimators and their mountings were of brass, but are now of cast-iron.

The pedestal, standards, and large wheel for the great counterpoise are of cast-iron.

The toothed-wheels for the lifting-mechanism, and the large screw-cut lifting-rod, are of gun-metal.

The rods which lift the friction-wheel-frame are of wrought iron, but the friction-wheels and their frame are of gun-metal.

The mercury-apparatus is of iron, (all the rods and long pieces being of wrought iron,) excepting only the counterpoises, which are of lead.

Every part of the machinery of the roof and shutters is of iron.

The following are the weights of the massive parts of the instrument:—

	lbs.
Two foundation-plates for the Y's	650
Two Y's, without the end-stops, &c.	210
End-stops and other attachment to the Y's	49
Axis of transit-circle, as composed of two pieces	892
Eyetube, without brass eyepiece, tube, &c.	189
Object-tube, without object-glass, cell, &c.	191
Hand-circle complete	108
Clamping circle	287
Division-circle	315
Galvanic rings and support	18
Clamping-arc for quicksilver-apparatus	511
Quicksilver-trough and attachments	179
Cylindrical lead counterpoise	520
Pins, &c., on which turn the two long bars that carry the quicksilver-apparatus	91
The two long bars	679
Two lead counterpoises at the top of the long bars	863
The intersecting arches, with their columns and brackets	994
Friction wheels, supporting-frames and rods, and levers	148
Lead counterpoises	260
Foundation-plates of the lifting-apparatus	854
Standards	840
Centre-frames	450
Gun-metal wheels, bushes, screws, chains, &c.	272
Large counterpoises and their carriers	2558
Large wheels for counterpoise-chains	210
Various spindles, bolts, nuts, &c., about	200

Of the weight of the optician's brass-work I have no precise information.

The plans for the general construction and arrangement of this instrument, were prepared by myself. The adoption of cast-iron, as the metal for the telescope-tube and axis, was first suggested to me by Charles May, Esq., of the firm of Ransomes and May, who constructed the massive parts of the instrument. The use of cast-iron, for the circle carrying the graduated band, was suggested by me, but was not finally adopted until I had satisfied myself, by trial of experimental iron circles furnished with bands of silver and exposed to the worst possible degree of rust, that no danger whatever was to be apprehended for the stability of the silver band. The details of the engineer's work were planned in every instance by Mr. May, who, with his able assistant, Mr. G. A. Biddell, gave incessant personal attention to the work. The silver bands were inserted by Mr. Simms, and four cardinal points were laid down by him while the instrument was mounted on temporary piers in Messrs. Ransomes and May's factory. The

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circle was then taken off the axis of the telescope and carried to Mr. Simms' factory, and was there mounted on Mr. Simms' admirable dividing-engine, by which all the divisions were cut.

The object-glass was ground by Mr. Simms. It was approved by me after trial in a temporary tube, before the other parts of the instrument were made, and is in my judgment a very excellent object-glass. The mounting of the object-glass, and the whole of the eyepiece-work, were by Mr. Simms. The illuminating-apparatus was arranged from the joint suggestions of Mr. Simms and myself. The galvanic brass rings on the axis were mounted by Mr. May, but those on the eyepiece-tube by Mr. Henley. The reading-microscopes, the axis-collimator, and the external-collimators, were planned by myself, but the work was executed by Mr. Simms. The nadir-eyepiece is on a construction long since adopted by Mr. Simms.

The following are the principal numerical determinations applying to the primary adjustments of the transit-circle, which were obtained shortly after its erection, and which from time to time require to be repeated.

(I.) To determine the absolute flexure of the telescope tube as attached to the axis.

Before mounting the 12-feet object-glass, an object-glass of about 3 feet focal length was mounted in the centre of the cube, and a cross of wires was fixed at the object-end, so that its image was formed upon the wires of the eyepiece. A better image would have been formed if two 6-feet object-glasses had been used with their external surfaces opposed to each other ; the image, however, was quite good enough for this determination. The place of the image at the eye-end was measured with the declination-micrometer when the telescope was horizontal with its object-end north, and again when the object-end was south. The difference of the two readings, found on 1850, September 2nd and September 14th (the two results being in precise accordance), was $0^{r}\cdot204=0\cdot00414$ inch ; one half of which, 0·00207 inch, was the effect of flexure in lowering one end with respect to the line passing through the centre and the other end. If the two ends yielded equally, the drop of each was sensibly $\frac{1}{1000}$ part of an inch.

This determination, it will be remarked, is one of curiosity only.

(II.) To determine the relative error of form of the pivots.

On December 10th, 1850, the large illuminating-lens and the gas-lamp were removed, and the 7-feet-telescope was planted upon two forks, of which one was placed in the opening in the pier, and the other in the opening through the wall of the Astronomer Royal's official room. The 7-feet telescope had been adjusted to focus by observation of stars, and the axis-collimator was adjusted to focus upon the 7-feet-telescope. Referring marks were made upon the tube of the 7-feet telescope and one of its forks, to ensure that the telescope was not turned. The micrometer was turned to positions exactly 90° apart by means of the graduated position-circle. In the first set of readings, the micrometer-head was above ; in the second, it was at the right hand. The readings increase as the wire moves towards the micrometer-head. The micrometer-head is divided into 60 parts.

The circle-readings are those given by the setting-pointer, and represent nearly the N.P.D. to which the telescope is directed. Each micrometer-result is the mean of three readings in three different revolutions.

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Circle Reading.	Vertical Micrometer Reading in first set.	Horizontal Micrometer Reading in second set.	Circle Reading.	Vertical Micrometer Reading in first set.	Horizontal Micrometer Reading in second set.
° ′	r	r	° ′	r	r
2.30	13.54·33	8.58·73	182.30	16. 9·87	8.20·53
7.30	53·60	52·47	187.30	11·73	25·67
12.30	53·30	46·33	192.30	12·77	31·87
17.30	52·13	40·37	197.30	12·77	37·97
22.30	52·30	34·30	202.30	12·67	44·57
27.30	52·90	27·97	207.30	12·23	50·87
32.30	53·77	21·77	212.30	11·20	8.56·10
37.30	55·17	15·37	217.30	9·60	9. 1·97
42.30	13.58·23	9·80	222.30	6·33	7·20
47.30	14. 1·07	8. 4·67	227.30	4·37	13·50
52.30	5·07	7.59·50	232.30	16. 0·97	18·83
57.30	8·83	53·90	237.30	15.57·80	24·73
62.30	12·47	48·67	242.30	53·70	29·40
67.30	17·47	44·83	247.30	49·00	33·90
72.30	21·90	41·53	252.30	44·87	36·93
77.30	27·77	38·47	257.30	39·27	40·67
82.30	32·97	35·17	262.30	35·00	43·50
87.30	38·40	33·17	267.30	29·33	45·73
92.30	44·87	32·13	272.30	22·80	47·73
97.30	50·60	30·50	277.30	16·97	48·93
102.30	14.56·47	30·10	282.30	10·53	50·17
107.30	15. 2·27	29·97	287.30	15. 4·50	51·27
112.30	8·60	30·77	292.30	14.58·23	50·90
117.30	14·77	31·23	297.30	51·80	49·70
122.30	21·17	32·50	302.30	45·77	48·60
127.30	27·17	34·53	307.30	40·17	46·43
132.30	33·13	36·47	312.30	34·17	44·20
137.30	38·13	38·63	317.30	28·70	41·10
142.30	43·27	41·73	322.30	23·43	37·93
147.30	48·03	45·17	327.30	19·33	34·57
152.30	52·20	49·37	332.30	13·90	30·97
157.30	15.56·80	53·17	337.30	9·87	26·13
162.30	16. 0·33	7.58·03	342.30	6·33	21·27
167.30	3·47	8. 3·87	347.30	14. 3·00	16·03
172.30	6·00	7·63	352.30	13.59·40	10·33
177.30	8·20	13·53	357·30	57·63	4·43

Grouping the numbers in each column by quadrants, and remarking that, if they were produced by excentricity of the point only, their formulæ would be—

Vertical measure = constant (1) + b cos. circle reading—c sin. circle reading.

Horizontal measure = constant (2) + b sin. circle reading + c cos. circle reading.

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we find from the vertical measures,—

$$\text{Constant (1)} = 15^{\mathrm{r}}.\ 3{\cdot}15$$
$$b = -\ 1.\ 6{\cdot}97$$
$$c = +\ 22{\cdot}09$$

and from the horizontal measures—

$$\text{Constant (2)} = 8.39{\cdot}60$$
$$b = -\ 1.\ 7{\cdot}14$$
$$c = +\ 21{\cdot}91$$

Adopting $b = -1^{\mathrm{r}}.7{\cdot}06$, $c = +22{\cdot}00$, computing the values of the two formulæ above for every observed circle-reading, and subtracting them from the numbers found by observation, we obtain the following residual quantities, which depend only on errors of the form of pivots, and on errors of observation.

RESIDUAL ERRORS.

Circle Reading.	Vertical Error.	Horizontal Error.	Circle Reading.	Vertical Error.	Horizontal Error.	Circle Reading.	Vertical Error.	Horizontal Error.	Circle Reading.	Vertical Error.	Horizontal Error.
° ′			° ′			° ′			° ′		
2.30	−0·87	+0·07	92.30	+0·78	+0·48	182.30	−1·23	−0·01	272.30	+0·59	+0·18
7.30	−0·21	−0·19	97.30	+0·51	+0·24	187.30	−0·76	−0·87	277.30	+0·76	−0·01
12.30	+0·38	−0·24	102.30	+0·29	+0·73	192.30	−0·61	−0·76	282.30	+0·41	+0·34
17.30	−0·44	−0·05	107.30	−0·06	+0·95	197.30	−0·96	−0·81	287.30	+0·53	+1·09
22.30	−0·47	+0·03	112.30	+0·12	+1·55	202.30	−0·86	−0·36	292.30	+0·41	+0·92
27.30	−0·61	−0·18	117.30	+0·17	+1·27	207.30	−0·56	−0·18	297.30	+0·10	+0·46
32.30	−1·00	−0·36	122.30	+0·55	+1·28	212.30	−0·33	−0·97	302.30	+0·09	+0·62
37.30	−1·37	−0·86	127.30	+0·65	+1·54	217.30	−0·16	−1·00	307.30	+0·39	+0·22
42.30	−0·62	−0·71	132.30	+0·89	+1·17	222.30	−1·12	−1·49	312.30	+0·11	+0·30
47.30	−0·55	−0·35	137.30	+0·40	+0·56	227.30	−0·31	−0·68	317.30	+0·13	−0·03
52.30	+0·21	−0·29	142.30	+0·31	+0·42	232.30	−0·47	−0·58	322.30	+0·09	+0·04
57.30	+0·27	−0·96	147.30	+0·14	+0·16	237.30	+0·06	+0·39	327.30	+0·92	+0·38
62.30	−0·21	−1·61	152.30	−0·27	+0·24	242.30	+0·08	+0·48	332.30	+0·07	+0·90
67.30	+0·31	−1·23	157.30	+0·11	−0·44	247.30	−0·14	+0·76	337.30	+0·26	+0·54
72.30	−0·09	−0·73	162.30	−0·16	−0·41	252.30	+0·56	−0·01	342.30	+0·52	+0·51
77.30	+0·61	−0·42	167.30	−0·39	+0·26	257.30	+0·13	+0·36	347.30	+0·56	+0·44
82.30	+0·38	−0·81	172.30	−0·77	−1·41	262.30	+1·29	+0·28	352.30	−0·13	+0·17
87.30	+0·15	−0·40	177.30	−0·98	−1·17	267.30	+1·28	+0·10	357.30	+0·51	−0·07

The value of the micrometer-scale was found by a process similar to that to be described shortly as applied to the collimators. It appeared that the unit in the expressions for the errors above=$0''{\cdot}527$.

Although the small residual numbers appear in some parts to follow a sort of law, I believe it to be quite accidental. It is not supported by observations made in 1851, February 7th, and subsequent times. The values for horizontal and vertical displacement cannot be explained on the known positions of the bearings on the Y's, by any determinate projections from the pivots. They are most likely due to some small error of the micrometer. The excentricity of the point relatively to the collimator lens required a greater range of the micrometer than was quite desirable. In the reduction of all celestial observations, I have considered the forms of the pivots as perfect. The pivots have been examined, with very similar results, in 1856, 1860, 1864, and 1867.

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(III.) To determine the errors of graduation of the divided circle.

It was found that the runs of the several microscopes were so nearly equal, that if the observations were made nearly on the same parts of the micrometer-range, they might be considered absolutely equal. The entire correction for runs might then be omitted.

1st. For the errors of every 60°.

The six cardinal divisions were brought successively under each of the six microscopes, till each division had been read 120 times. The readings for each division were collected, and the means were taken. The excess of reading of each was found as follows, assuming that of 0° to be 0r·054.

Divisions	0°	60°	120°	180°	240°	300°
Errors	0r·054	0r·074	0r·079	0r·050	0r·064	0r·082

2nd. For the errors of every 20°.

The microscopes a and b (Plates VII and VIII,) were used in conjunction with A and B ; and, in order that no error might be produced by accidental displacement of the center, the four microscopes were always read at the same time. The reduction was effected in the following manner :—By the mean of 20 observations in each case we have

Division under A.	Division under a.	Reading of A.	Reading of a.
0°	340°	0r·259	0r·192
340	320	0r.264	0r·194
320	300	0r·234	0r·158

Also (by the preceding operation), error of 0° = 0r·054.
error of 300° = 0r·082.

Then 3 × error of 340° = 2 × 0r·054	And 3 × error of 320° = 1 × 0r·054
+ 1 × 0r·082	+ 2 × 0r·082
+ 2 × 0r·192	+ 1 × 0r·192
+ 1 × 0r·264	+ 1 × 0r·194
+ 1 × 0r·234	+ 2 × 0r·234
− 2 × 0r·259	− 1 × 0r·259
− 1 × 0r·194	− 1 × 0r·264
− 1 × 0r·158	− 2 × 0r·158
Whence error of 340° = 0r·067	Error of 320° = 0r·078.

The same method was applied to every arc of 20°.

3rd. To find the errors of every 5°.

The errors for every 20° having been found by the preceding operations, the errors of every 5° could be found by the pairs of microscopes A, α, B, β, of which the interval is 25°. For, starting from any multiple of 20°, as 40°, then successive additions of 25° bring us to 65°, 90°, 115°, and 140°, the last of which is included in the series of multiples of 20°. The errors of the extremes are therefore known, and therefore those of the three intermediates can be found. And every 5° on the circle can be reached in this way, by starting from the proper multiple of 20°. It must be remarked for understanding the change in the order of numbers in the following supposed observations, that the division under α is *greater* in its number of degrees than that under A (that under a having been *less*.)

Suppose then that we have these observations :

Degree under A.	Degree under α	Micrometer reading of A.	Micrometer reading of α
θ	$\theta + 25°$	a	b
$\theta + 25°$	$\theta + 50°$	c	d
$\theta + 50°$	$\theta + 75°$	e	f
$\theta + 75°$	$\theta + 100°$	g	h

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And suppose that the errors of the five divisions, by which they read too much, are x_0, x_1, x_2, x_3, x_4; x_0 and x_4 being known by the preceding operations. Then

$$4x_1 = 3x_0 + x_4 + 3b + c + e + g - (3a + d + f + h)$$
$$4x_2 = 2x_0 + 2x_4 + 2b + 2d + 2e + 2g - (2a + 2c + 2f + 2h)$$
$$4x_3 = x_0 + 3x_4 + b + d + f + 3g - (a + c + e + 3h)$$

Every number used was the mean of 16 readings. The opposite microscopes were always read at the same time.

4th. To find the errors of every 1°.

The pointer-microscope P was removed, and in its stead was placed a microscope with a micrometer, in all respects similar to the other microscope-micrometers, but having two object-glasses side by side, at such a distance that the images of divisions 1° apart on the limb of the circle fell very nearly on the same point of the micrometer. An assistant was stationed to cover alternately one and the other of these object-glasses, and then the two images were observed alternately, with a very small movement of the micrometer. Every fifth repetition of this process brought one of the series of 5° under view. Suppose that the observations were—

First degree.	Second degree.	Micrometer reading for first degree.	Micrometer reading for second degree.
θ	$\theta + 1°$	a	b
$\theta + 1°$	$\theta + 2°$	c	d
$\theta + 2°$	$\theta + 3°$	e	f
$\theta + 3°$	$\theta + 4°$	g	h
$\theta + 4°$	$\theta + 5°$	i	k

and suppose the errors (excess of reading,) to be x_0, x_1, x_2, x_3, x_4, x_5; x_0 and x_5 being known. Then the formulæ are

$$5x_1 = 4x_0 + x_4 + 4b + c + e + g + i - (4a + d + f + h + k)$$
$$5x_2 = 3x_0 + 2x_4 + 3b + 3d + 2e + 2g + 2i - (3a + 3c + 2f + 2h + 2k)$$
$$5x_3 = 2x_0 + 3x_4 + 2b + 2d + 2f + 3g + 3i - (2a + 2c + 2e + 3h + 3k)$$
$$5x_4 = x_0 + 4x_4 + b + d + f + h + 4i - (a + c + e + g + 4k)$$

Each number used was the mean of four readings.

The three first sections of this operation were unexceptionably good. In the fourth there was a slight defect of focal adjustment of the microscopes, which has probably produced no sensible error of result; I propose, however, to repeat that part of the operation.

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The final result for errors of division for every degree is as follows ; ($1^r = 61''\cdot4$ nearly.) :

Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.	Degree.	Excess of Reading.
°	r	°	r	°	r	°	r	°	r	°	r	°	r	°	r
0	0·054	45	0·057	90	0·076	135	0·085	180	0·050	225	0·029	270	0·073	315	0·070
1	·053	46	·062	91	·078	136	·087	181	·046	226	·033	271	·071	316	·071
2	·050	47	·066	92	·081	137	·095	182	·043	227	·039	272	·061	317	·075
3	·053	48	·073	93	·073	138	·089	183	·045	228	·041	273	·059	318	·077
4	·052	49	·069	94	·078	139	·082	184	·047	229	·050	274	·058	319	·071
5	·053	50	·061	95	·073	140	·081	185	·042	230	·053	275	·063	320	·078
6	·053	51	·058	96	·072	141	·084	186	·037	231	·054	276	·063	321	·074
7	·051	52	·064	97	·071	142	·083	187	·043	232	·058	277	·067	322	·069
8	·054	53	·086	98	·070	143	·091	188	·045	233	·062	278	·072	323	·079
9	·050	54	·071	99	·075	144	·086	189	·038	234	·058	279	·072	324	·075
10	·052	55	·076	100	·075	145	·080	190	·028	235	·052	280	·066	325	·075
11	·061	56	·075	101	·067	146	·073	191	·019	236	·040	281	·068	326	·073
12	·061	57	·077	102	·073	147	·078	192	·026	237	·043	282	·069	327	·065
13	·057	58	·080	103	·069	148	·078	193	·034	238	·052	283	·070	328	·063
14	·065	59	·079	104	·065	149	·072	194	·032	239	·061	284	·065	329	·067
15	·058	60	·074	105	·064	150	·073	195	·036	240	·064	285	·059	330	·063
16	·060	61	·072	106	·066	151	·068	196	·038	241	·072	286	·061	331	·057
17	·055	62	·065	107	·061	152	·073	197	·036	242	·069	287	·055	332	·068
18	·062	63	·064	108	·059	153	·081	198	·039	243	·073	288	·057	333	·072
19	·062	64	·074	109	·067	154	·081	199	·044	244	·064	289	·057	334	·074
20	·064	65	·067	110	·065	155	·087	200	·038	245	·062	290	·055	335	·075
21	·052	66	·063	111	·064	156	·088	201	·046	246	·052	291	·056	336	·076
22	·052	67	·060	112	·067	157	·075	202	·044	247	·045	292	·069	337	·070
23	·051	68	·062	113	·068	158	·069	203	·040	248	·038	293	·065	338	·067
24	·055	69	·068	114	·073	159	·070	204	·040	249	·043	294	·072	339	·066
25	·053	70	·065	115	·072	160	·072	205	·043	250	·046	295	·076	340	·067
26	·062	71	·060	116	·078	161	·067	206	·041	251	·045	296	·072	341	·069
27	·057	72	·054	117	·078	162	·061	207	·045	252	·046	297	·070	342	·076
28	·057	73	·047	118	·071	163	·059	208	·045	253	·050	298	·063	343	·073
29	·060	74	·045	119	·077	164	·060	209	·045	254	·054	299	·065	344	·069
30	·062	75	·058	120	·079	165	·067	210	·052	255	·061	300	·082	345	·070
31	·069	76	·056	121	·084	166	·065	211	·052	256	·066	301	·079	346	·067
32	·065	77	·055	122	·087	167	·062	212	·042	257	·069	302	·074	347	·068
33	·067	78	·056	123	·095	168	·056	213	·042	258	·065	303	·078	348	·068
34	·064	79	·061	124	·100	169	·057	214	·037	259	·058	304	·083	349	·061
35	·061	80	·065	125	·088	170	·052	215	·031	260	·065	305	·079	350	·053
36	·055	81	·072	126	·093	171	·055	216	·039	261	·074	306	·080	351	·050
37	·054	82	·076	127	·090	172	·053	217	·034	262	·073	307	·080	352	·044
38	·055	83	·077	128	·087	173	·049	218	·040	263	·074	308	·077	353	·049
39	·066	84	·077	129	·082	174	·046	219	·031	264	·076	309	·074	354	·047
40	·065	85	·077	130	·079	175	·041	220	·035	265	·078	310	·070	355	·041
41	·068	86	·075	131	·087	176	·044	221	·034	266	·079	311	·077	356	·046
42	·072	87	·083	132	·070	177	·057	222	·031	267	·086	312	·073	357	·050
43	·070	88	·074	133	·076	178	·053	223	·035	268	·083	313	·074	358	·053
44	·062	89	·076	134	·080	179	·051	224	·036	269	·075	314	·075	359	·054

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5th. Apparatus for finding the error of every 5′. The micrometer of the last-mentioned microscope is furnished with two sets of wire crosses, at an interval of 5′ nearly. It was intended to use these, by a small motion of the micrometer, for the measure of every space of 5′; and, after every 12 measures, the divisions in the series of 1° would be brought under the microscope, and the errors of the intermediate divisions would be ascertained by proper formulæ. But after examination of the generally regular progress of the trifling errors in the 1° series; and after consideration of the great security which is given for the regular progress of the errors of intermediate divisions by a well-made dividing-engine, I judged this operation to be unnecessary. [This operation has, subsequently, been performed for several of the divisions most frequently used.]

A complete redetermination of the divisions' errors was made in 1856–57.

(IV.) To determine the values of the graduations of the micrometers, and the intervals of wires in the telescope-eyepiece.

For the declination-micrometer, one circle-reading was taken by directing the telescope to one collimator, and observing its nearly-horizontal wire with a small reading of the declination-micrometer, and another by observing the same wire with a large reading of the declination-micrometer; the microscope-micrometers being read and corrected for runs, &c. The result ought to be the same in the two cases when the proper value is given to the revolutions of the micrometer. This consideration gives a simple equation for the value of 1^r. A series of experiments, including 270 revolutions of the micrometer, gave $1^r = 29''\cdot626$.

[The very near approach of this value to the half-value of one revolution of the micrometers of the circle-microscopes sometimes produced inconvenience, in cases where mistake of reading had been made, and where it was difficult to decide which micrometer had been erroneously read. A new micrometer has now been mounted, the value of whose revolution is $34''\cdot526$.]

For the transit-micrometer, the eyepiece sliding-tube of the telescope was turned 90° in its fixed tube, and the same process was employed. The result of the experiment on 420 revolutions was $1^r = 14''\cdot781$.

For the intervals of transit-wires, the eyepiece-sliding tube being in the same position, each wire was brought upon the image of the nearly horizontal wire of a collimator, partly by movement of the instrument and partly by movement of the transit micrometer-screw. The microscope-micrometers were read. The combination of values of the microscope-micrometers and of the telescope-micrometers being made, a series of numbers is obtained for the different wires, whose differences give the intervals of the wires. [In later years, however, the intervals have usually been determined from transits of stars.]

(V.) To determine the values of the collimator-micrometers, and the micrometer of the 7-feet telescope.

The south collimator was turned 90°, so that the range of its micrometer, as well as that of the north collimator, was up and down. The 7-feet telescope, when it was the subject of experiment, was placed in the same position in the forks of one of the collimators. The wire of each was placed in different positions, and the reading of its image was taken as viewed by the transit-telescope and read off by the microscope-micrometers and the telescope-micrometer. The results, from abont 200 revolutions in each case, were; south collimator, $1^r = 32''\cdot29$; north collimator, $1^r = 31''\cdot45$; 7-feet telescope, $1^r = 31''\cdot62$. [The results for the new collimators, are; south collimator, $1^r = 24''\cdot17$; north collimator, $1^r = 24''\cdot24$.]

(VI.) To determine the astronomical flexure of the transit-telescope.

On December 30, 1850, the instrument was raised, and the south collimator was viewed by the north collimator. The nearly-horizontal wire of the north collimator was brought by its micrometer screw upon that of the south collimator 20 times, and the reading was taken each time. The mean of the readings was $0^r\cdot570$. The micrometer was set to this reading, the instrument was lowered, and the two collimator-wires were observed by the transit-circle. The reading for the south collimator was found to be 89° 46′ 15″·52; that for the north collimator 269° 46′ 16″·35. Half the difference of the seconds, or 0″·41, is the effect of flexure in diminishing apparent zenith distances near the horizon. The results of similar operations were, on 1851, February 5, +0″·88; on 1852, December 23, +0″·20; 1857, January 5, +0″·46; 1857, January 21, +0″·66; 1860, September 1, +0″·67; 1864, September 7, +0″·76. [Since the perforation of the plates i, the values found are, on 1867, April 25, −0″·34; on 1867, May 8, −0″·31; and on 1867, May 13, −0″·37.]

(VII.) To determine the line of collimation, in reference to transit observations.

As this operation is repeated every day, it will suffice to take any day as an example. On February 7, 1853, the instrument was raised, the north collimator was viewed by the south collimator, the nearly-vertical wire of one was placed on the image of

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the other by means of the horizontal micrometer-screw of the south collimator, and the reading of the micrometer was registered. This was repeated six times; the mean of the readings was taken, and found $=0^{r}\cdot 630$, and the microscope was set to the reading $0^{r}\cdot 630$. Then the instrument was lowered, and the two nearly-vertical wires were observed with it, the wire-frame of the transit-telescope being moved by the transit-micrometer till the middle vertical wire coincided successively with the image of the nearly-vertical wire of each collimator. These measures were repeated six times for each collimator, the transit micrometer being read each time, and the means of the readings being taken. The means were—

Reading for south collimator - - -	$31^{r}\cdot 300$
Reading for north collimator - -	$31\ \cdot 521$

The mean of these, or $31^{r}\cdot 411$, is the reading for the line of collimation; and when the transit-micrometer is set to this reading, it may be considered that the line from the focal centre of the object-glass to the middle transit-wire is sensibly at right angles to the axis of the instrument.

(VIII.) To determine the inclination of the axis of the transit-telescope to the plane of the horizon.

As in the last instance, an example will suffice. On Nov. 10, 1852, the nadir-eyepiece was mounted, and the wires were observed by reflexion in quicksilver. By the transit-micrometer, the middle wire and its image formed by reflexion were brought into contact six times successively on the right and left sides, the micrometer was read, and the mean was taken. The mean was $31^{r}\cdot 531$. The reading for the line of collimation had been found $31^{r}\cdot 358$. The difference, $0^{r}\cdot 173$ or $2''\cdot 55$, is the inclination of the axis. On considering the position of the micrometer-screw and the direction in which the wires are moved when the reading of the micrometer increases, it appeared that, when the reading for coincidence of direct and reflected images is greater than that for the line of collimation, the east end of the axis is higher than the west end, and the correction to observed transits will be negative. The error, therefore, in this instance is $-2''\cdot 55$.

(IX.) To determine the azimuthal error of the transit-telescope.

For this purpose, reference is made in the first instance to observations of circumpolar stars, as for the former transit-instrument. Advantage is taken, however, of the presumed stability of the north collimator, in this manner. Every satisfactory determination of azimuth (and none but those founded on upper and lower consecutive passages of a circumpolar star are admitted for this purpose) gives a determination of azimuth of the north collimator. The mean of several such results gives a very accurate determination of that azimuth (supposed constant), and then every observation of the north collimator gives a new determination of the azimuth of the transit-telescope, applicable to the time of that observation. [In later years, the azimuthal error has been determined exclusively by double transit of a circumpolar star, or by single transit of a circumpolar star combined with transit of a clock star.]

(X.) To determine the zenith-point, or circle-reading corresponding to the zenithal position of the telescope.

This is done, either by observing the declination wire by reflection, by means of the nadir eyepiece (an operation which is repeated every day), or by observing stars by reflexion (for which purpose, when the weather permits, a north star and a south star are observed every evening). The two processes are in no respect different from those which have been employed with the mural circle and other instruments.

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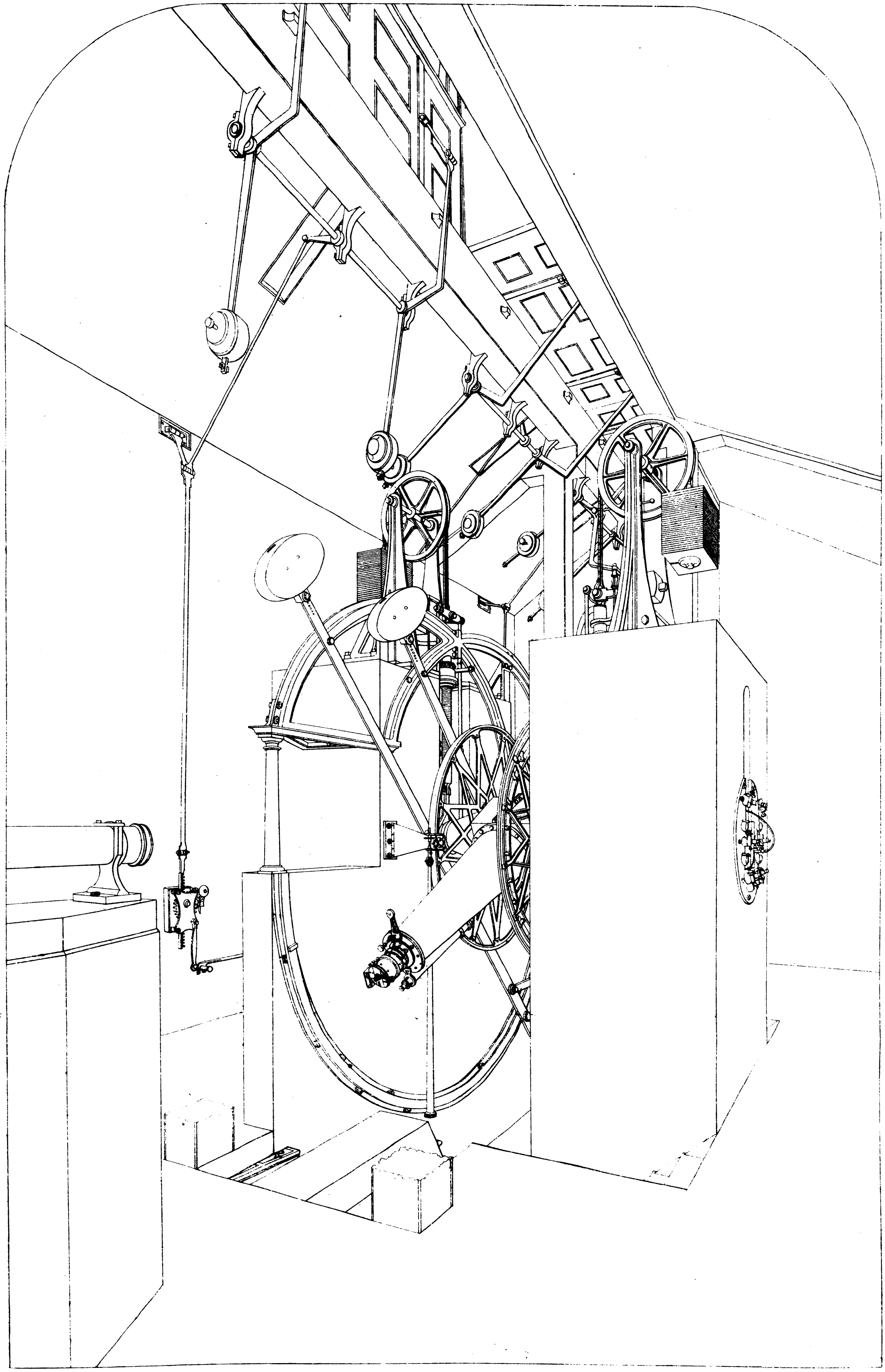

VIEW OF THE TRANSIT-CIRCLE OF THE ROYAL OBSERVATORY GREENWICH FROM THE NORTH WEST

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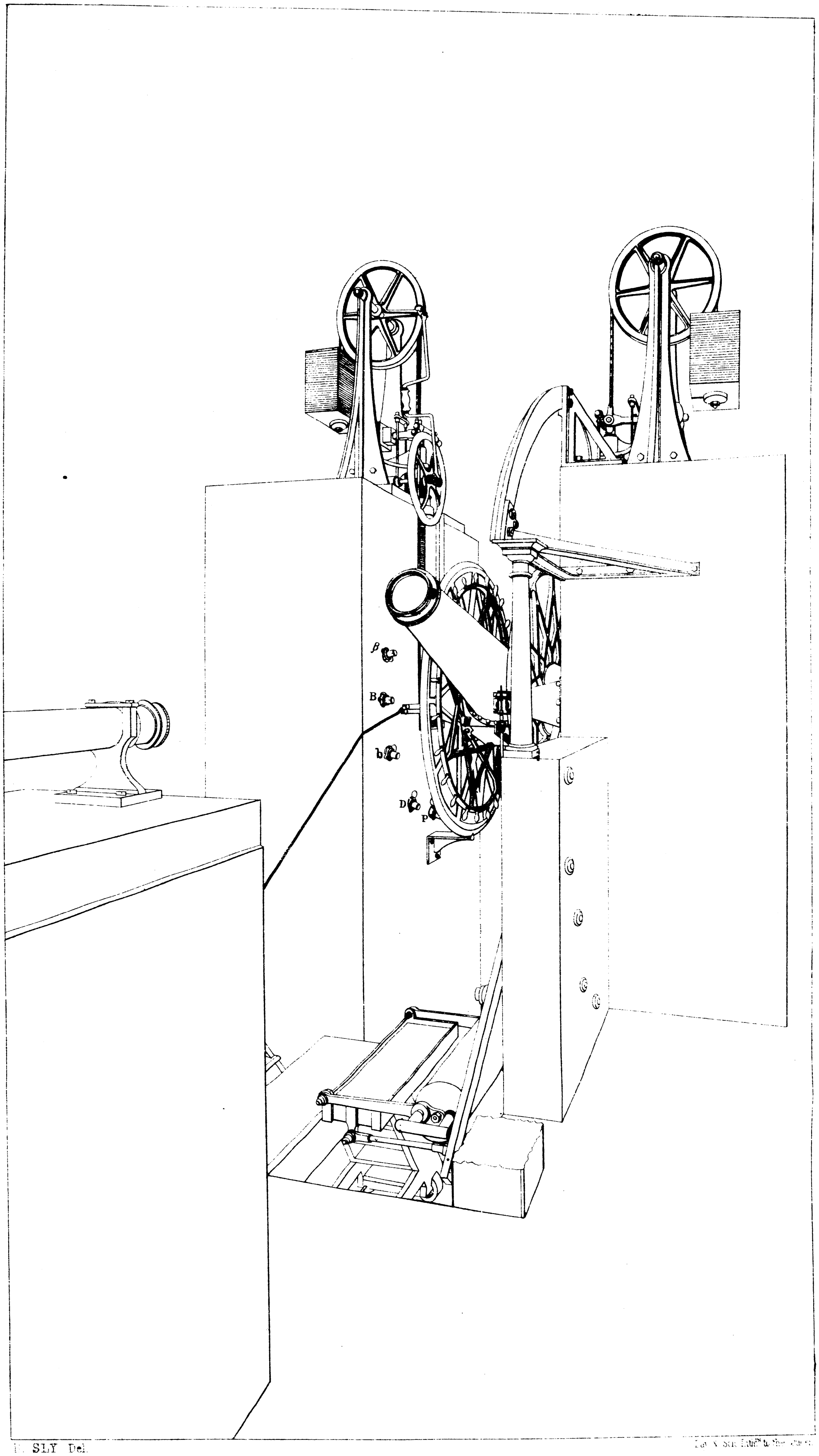

SLY Del.

VIEW OF THE TRANSIT-CIRCLE OF THE ROYAL OBSERVATORY GREENWICH, FROM THE SOUTH EAST

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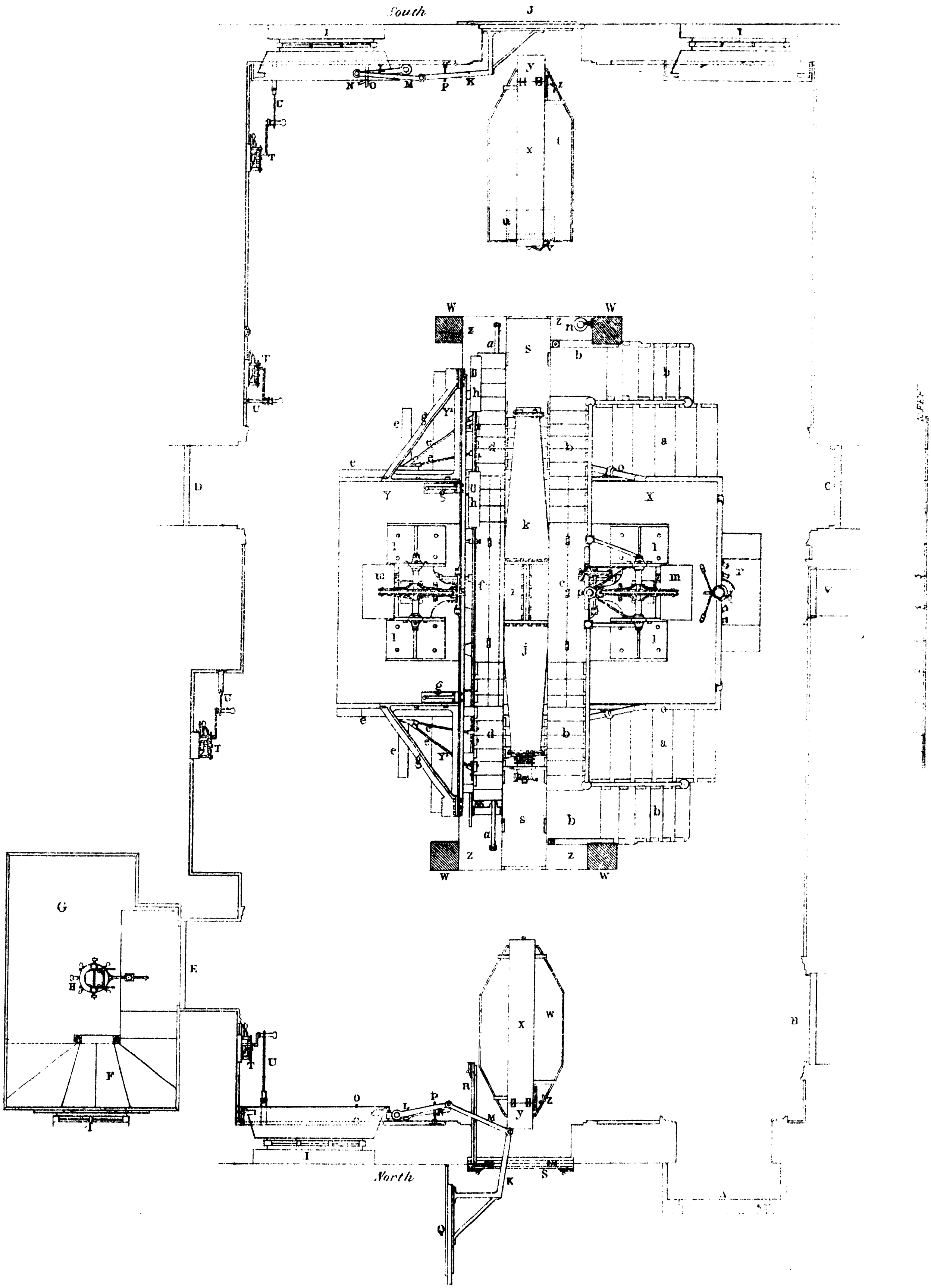

GROUND-PLAN OF TRANSIT CIRCLE-ROOM OF THE ROYAL OBSERVATORY, GREENWICH, AND VIEW OF TRANSIT CIRCLE AS FROM ABOVE.

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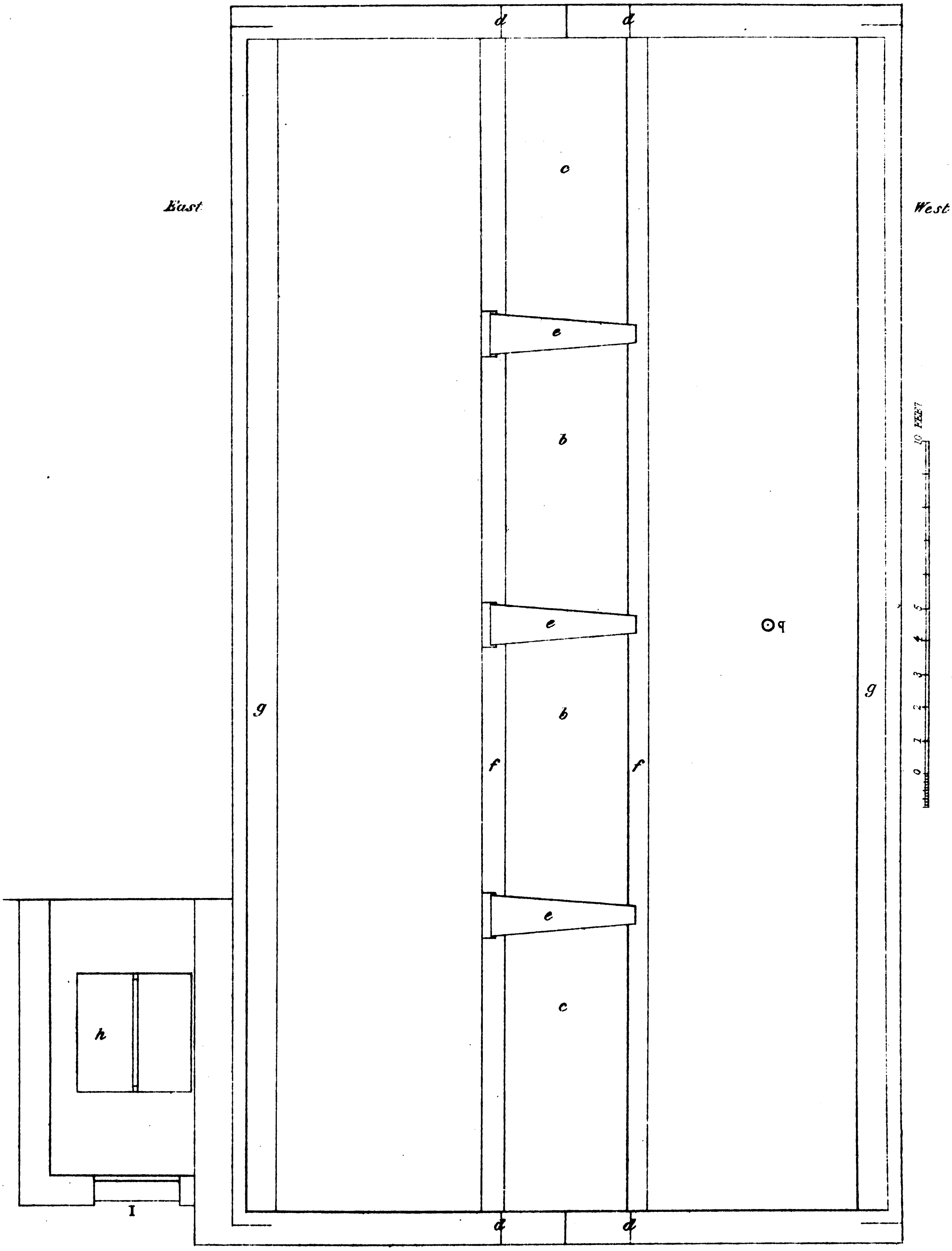
GREENWICH OBSERVATIONS 1852. DESCRIPTION OF TRANSIT-CIRCLE, PLATE IV.



PLAN OF ROOF OF TRANSIT-CIRCLE-ROOM &c. AT THE ROYAL OBSERVATORY, GREENWICH.

B. SLY. Del.

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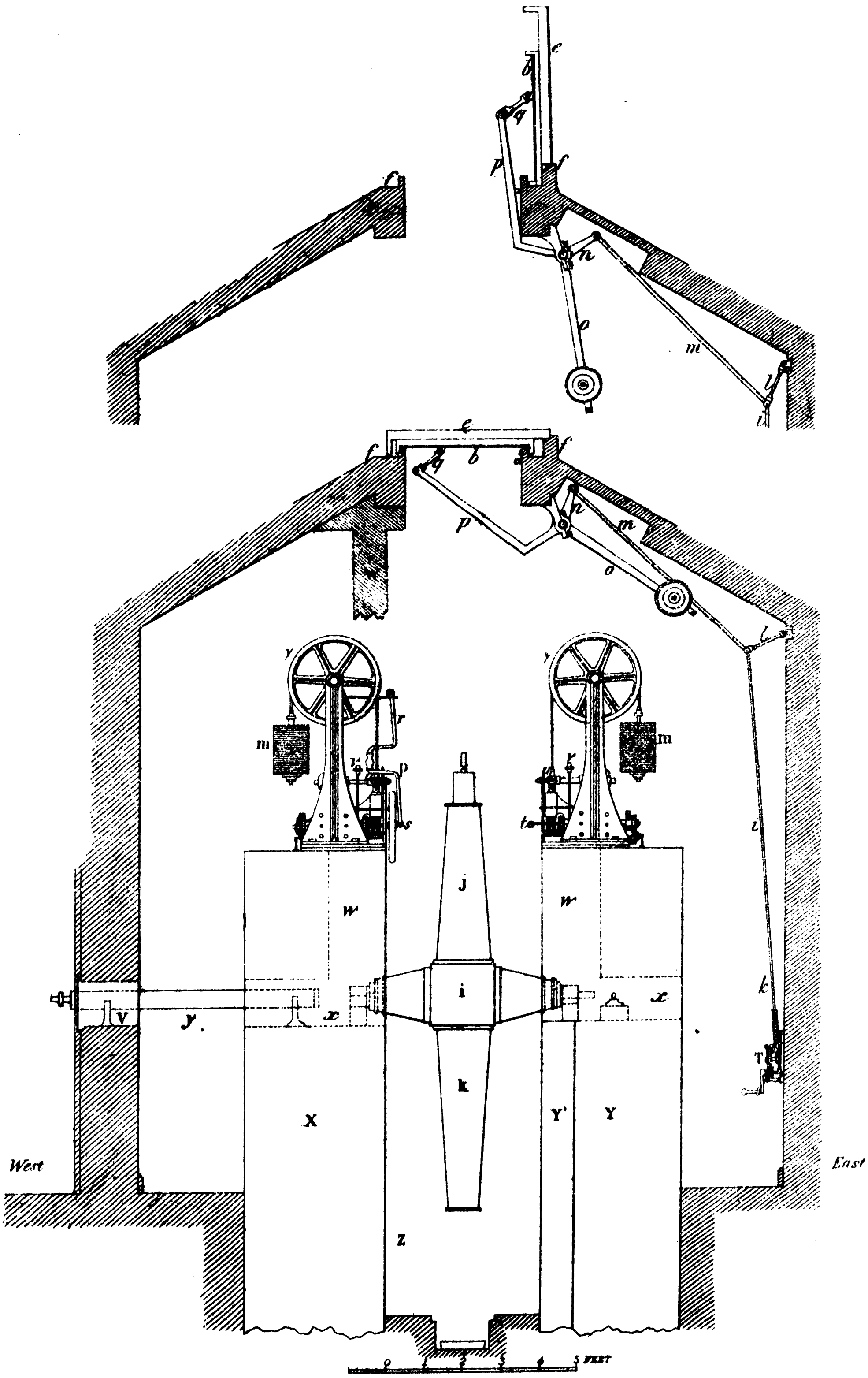

B. SLY Del.

Day & Son Lith[rs] to the Queen

TRANSVERSAL SECTION OF TRANSIT-CIRCLE-ROOM OF THE ROYAL OBSERVATORY, GREENWICH WITH A PART OF THE INSTRUMENT.

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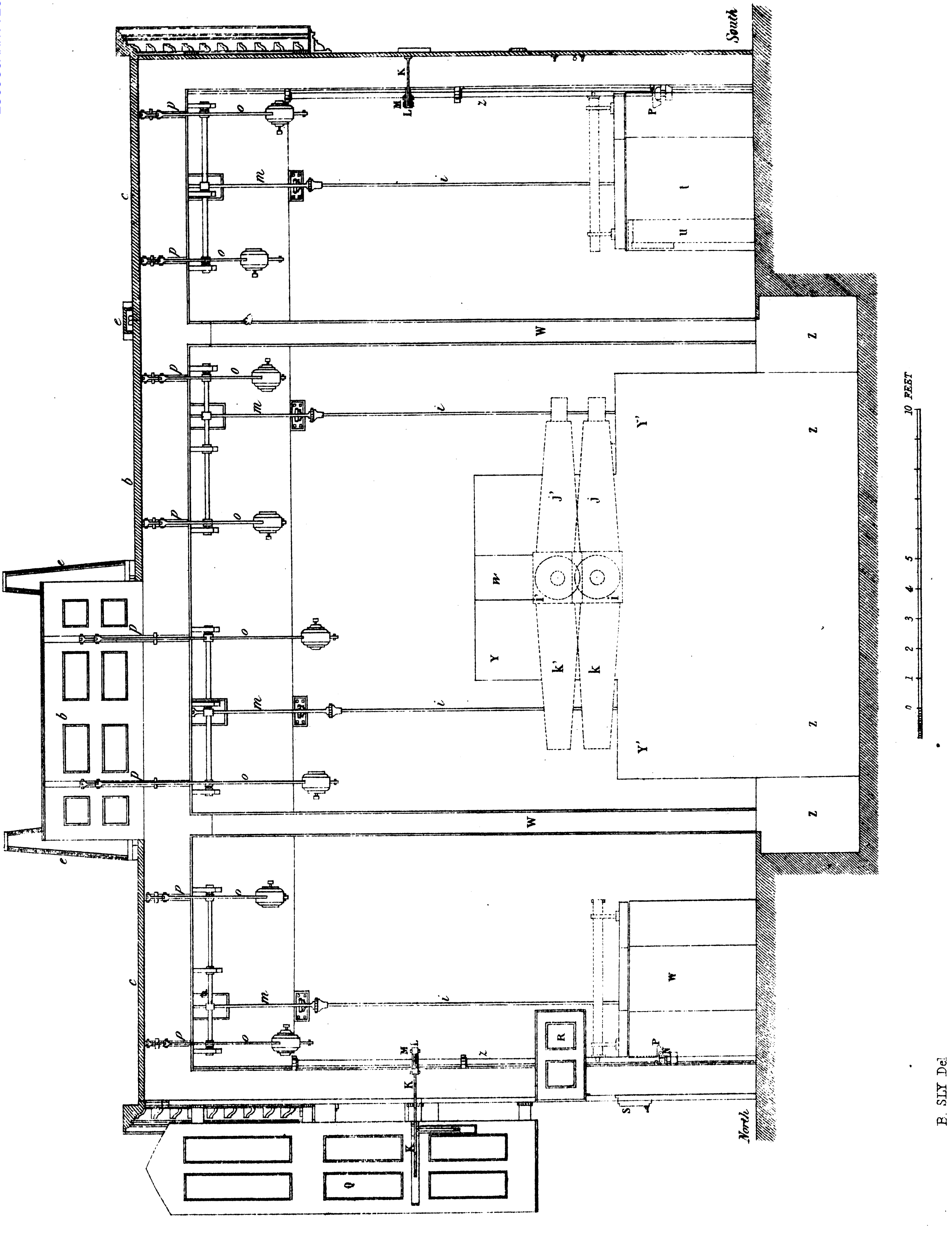

LONGITUDINAL SECTION OF TRANSIT CIRCLE ROOM OF ROYAL OBSERVATORY, GREENWICH.

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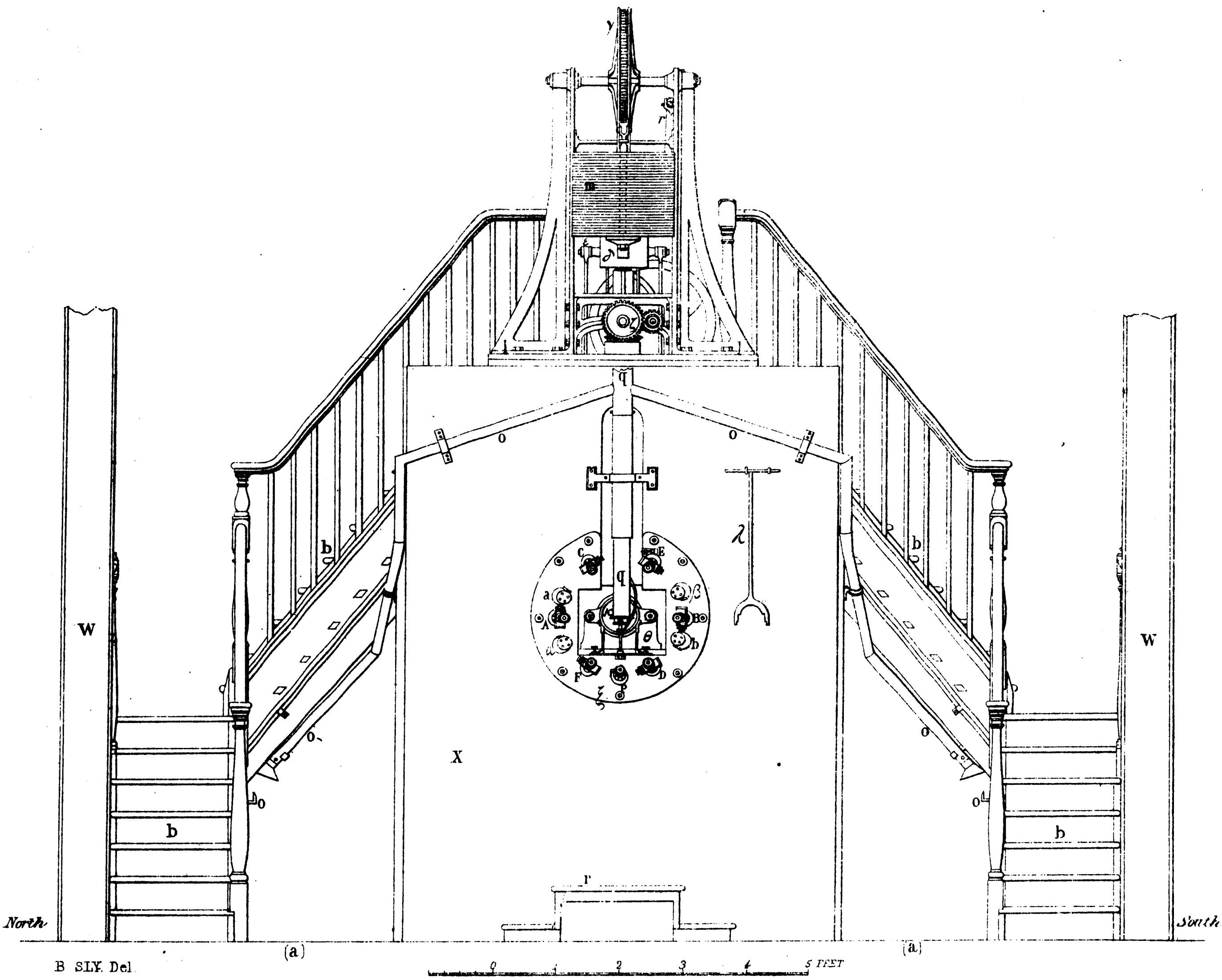

WESTERN FACE OF WESTERN PIER OF TRANSIT-CIRCLE OF ROYAL OBSERVATORY, GREENWICH.

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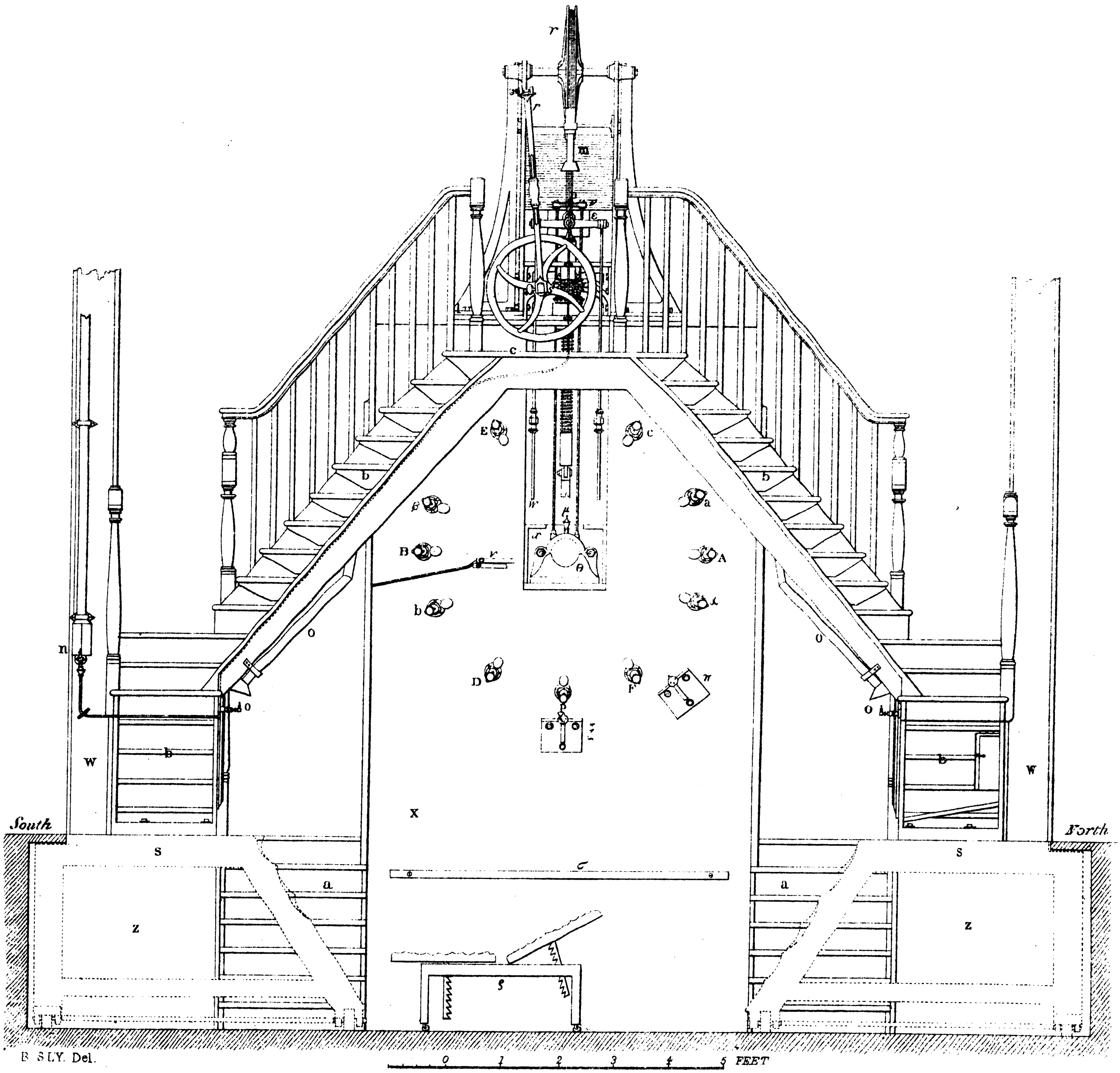

EASTERN FACE OF WESTERN PIER OF TRANSIT-CIRCLE AT THE ROYAL OBSERVATORY, GREENWICH.

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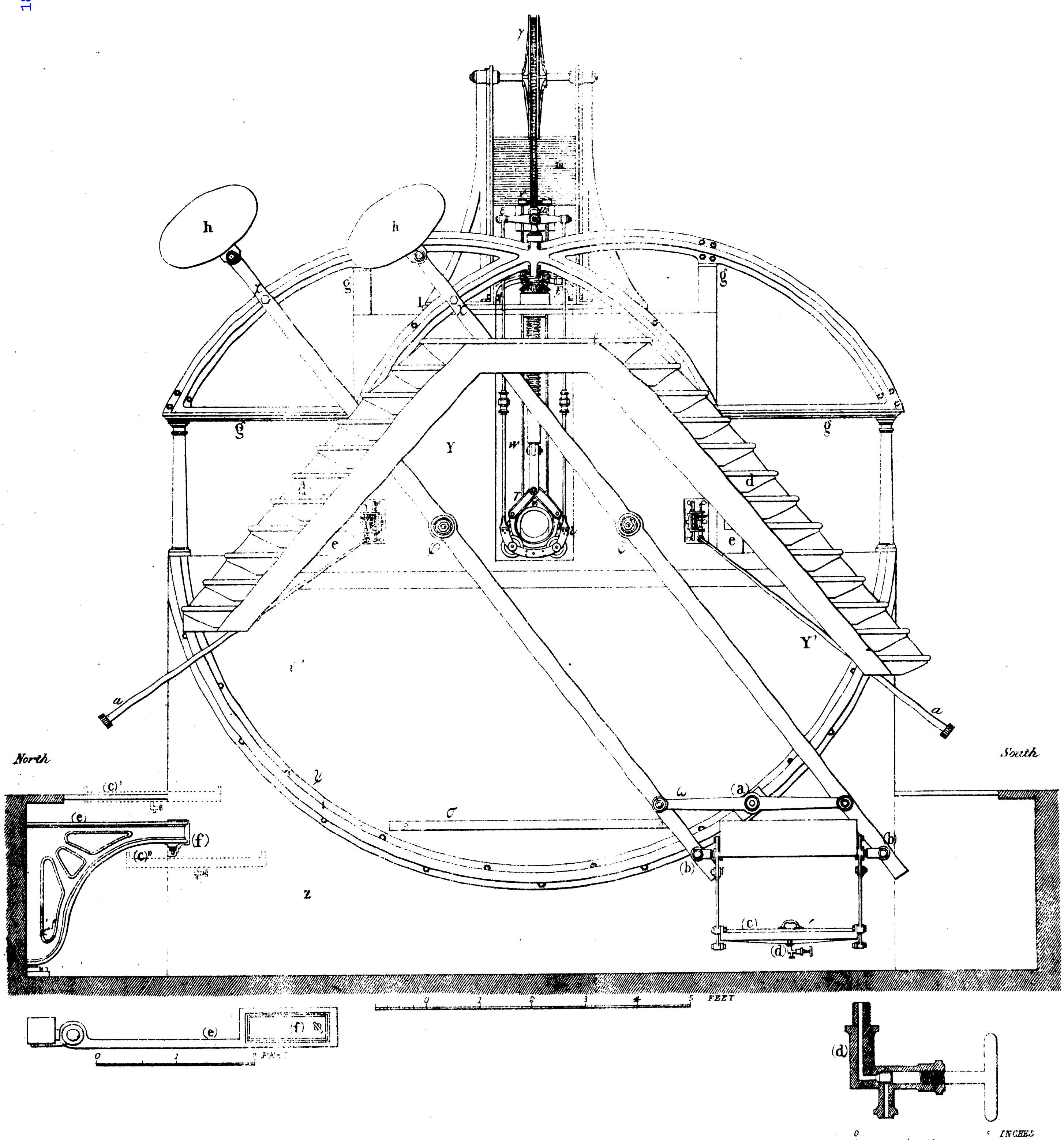

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WESTERN FACE OF EASTERN PIER OF TRANSIT-CIRCLE AT THE ROYAL OBSERVATORY GREENWICH

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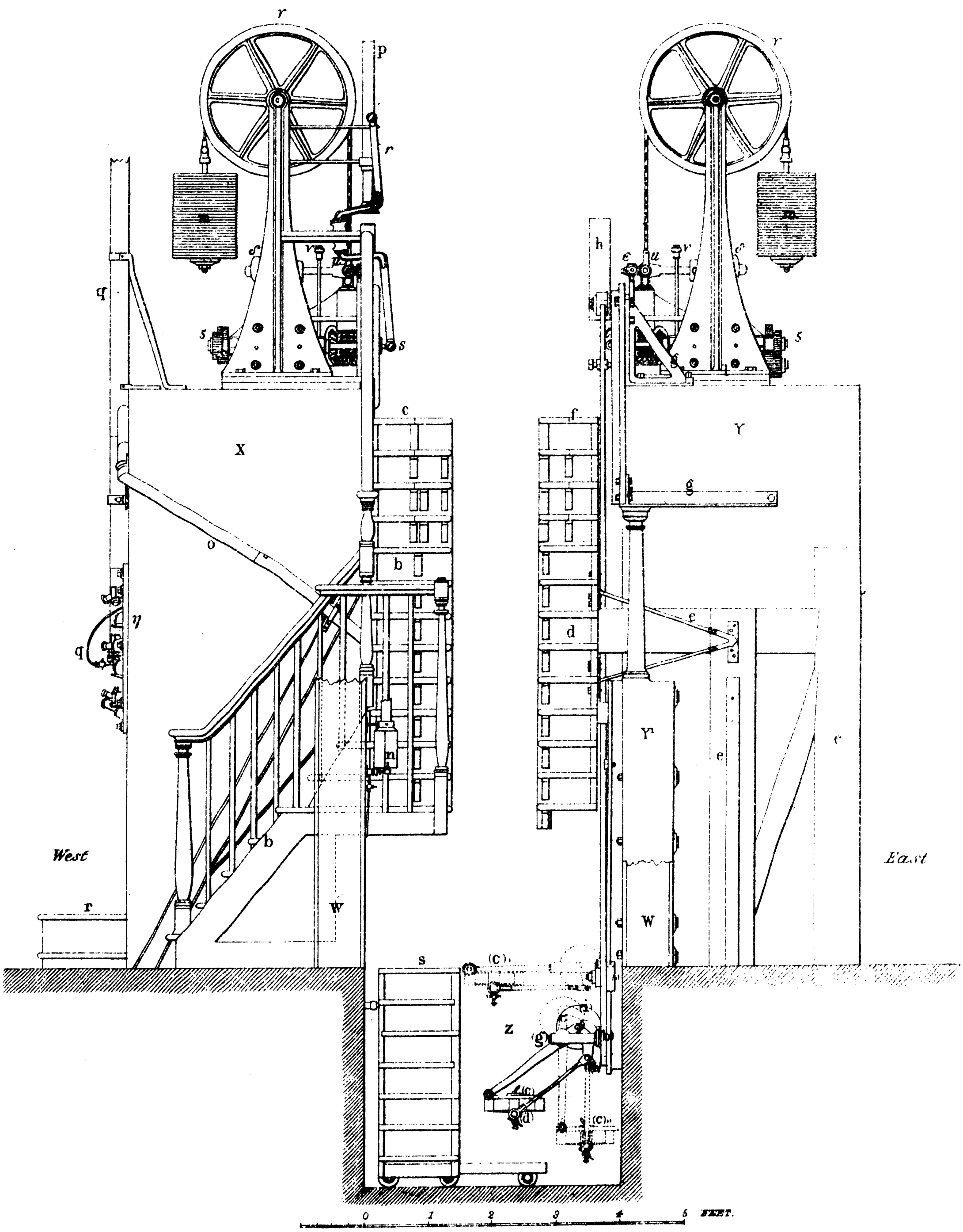
GREENWICH OBSERVATIONS 1852. DESCRIPTION OF TRANSIT-CIRCLE. PLATE X.



SOUTHERN VIEW OF PIERS, WITH SECTION OF PIT, OF THE TRANSIT-CIRCLE, AT THE ROYAL OBSERVATORY, GREENWICH.

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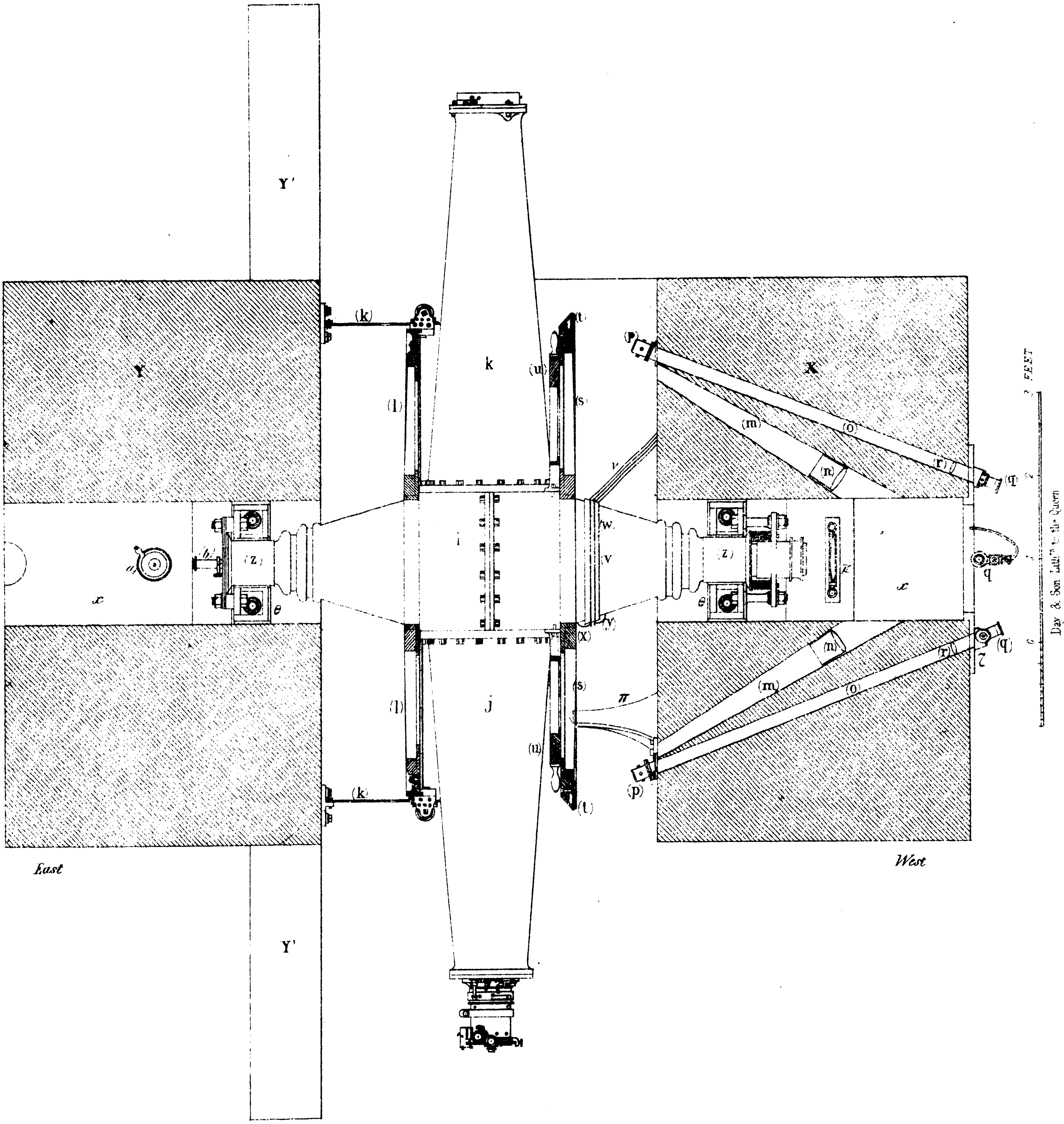

HORIZONTAL SECTION OF PIERS &C. AT THE HEIGHT OF THE CENTRE OF THE TRANSIT-CIRCLE AT THE ROYAL OBSERVATORY, GREENWICH.

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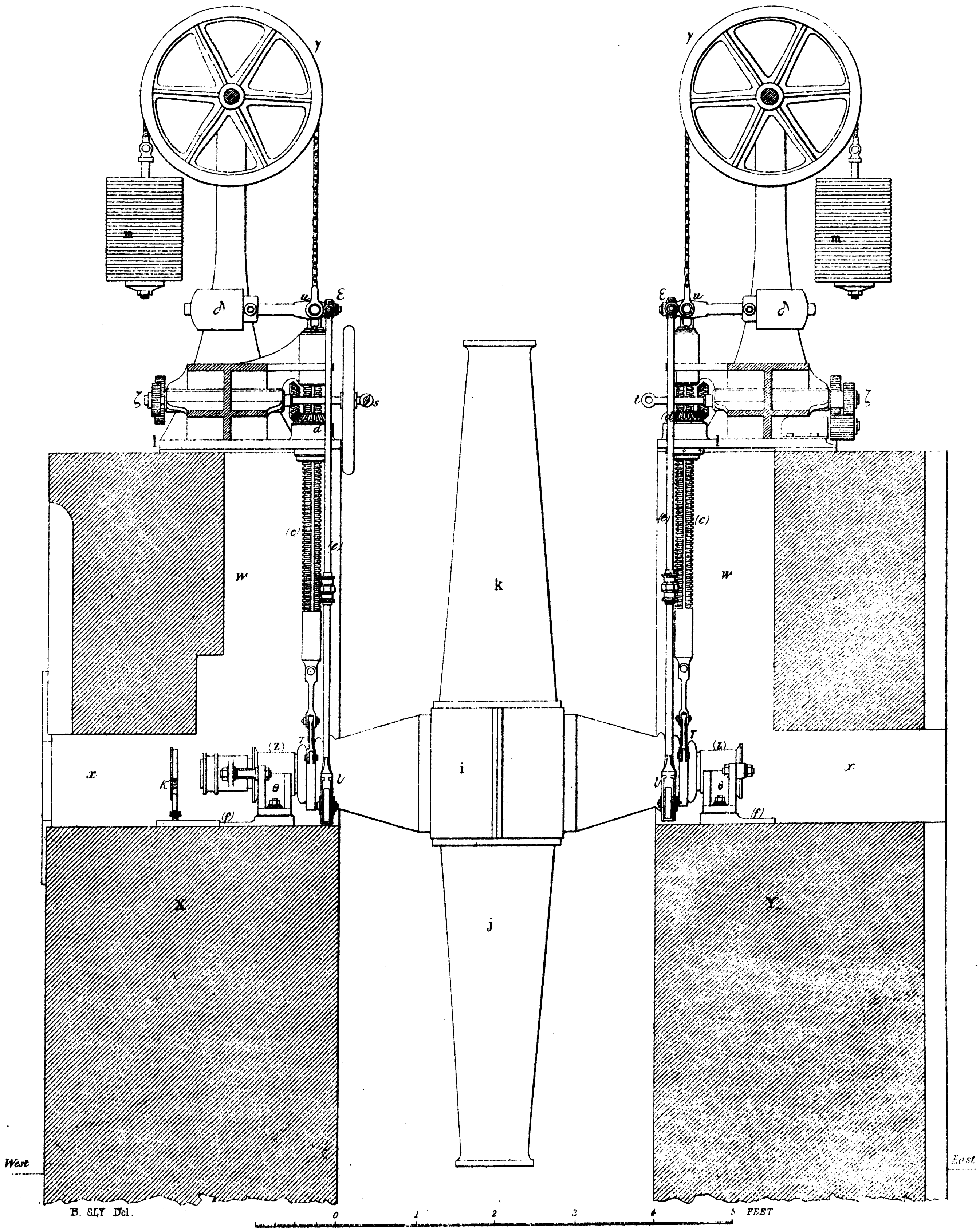

B. SLY Del.

EAST AND WEST VERTICAL SECTION THROUGH THE MIDDLE OF THE PIERS OF THE TRANSIT-CIRCLE AT THE ROYAL OBSERVATORY GREENWICH.

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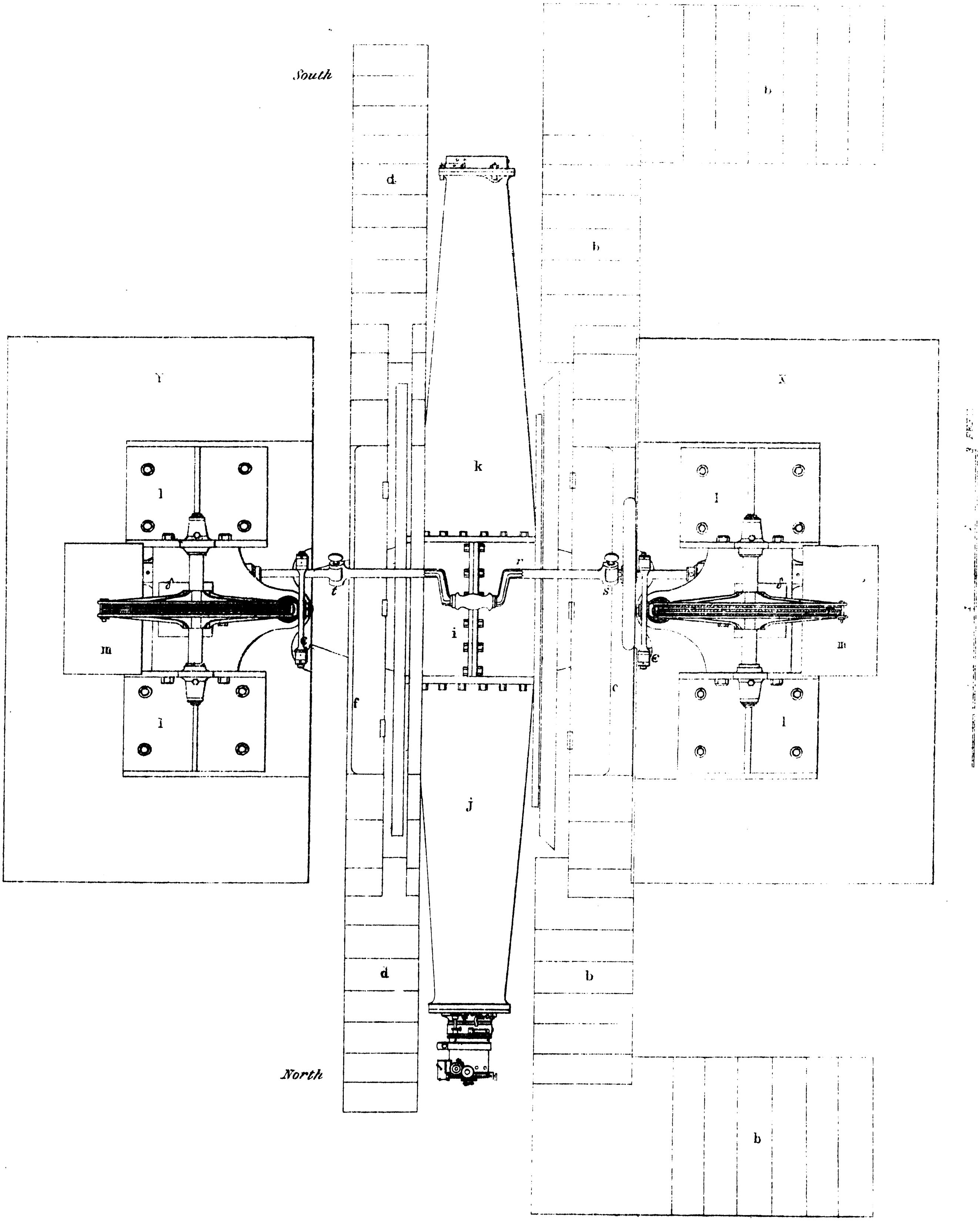

VIEW (FROM ABOVE) OF THE MACHINERY AS CONNECTED FOR RAISING THE TRANSIT-CIRCLE AT THE ROYAL OBSERVATORY, GREENWICH

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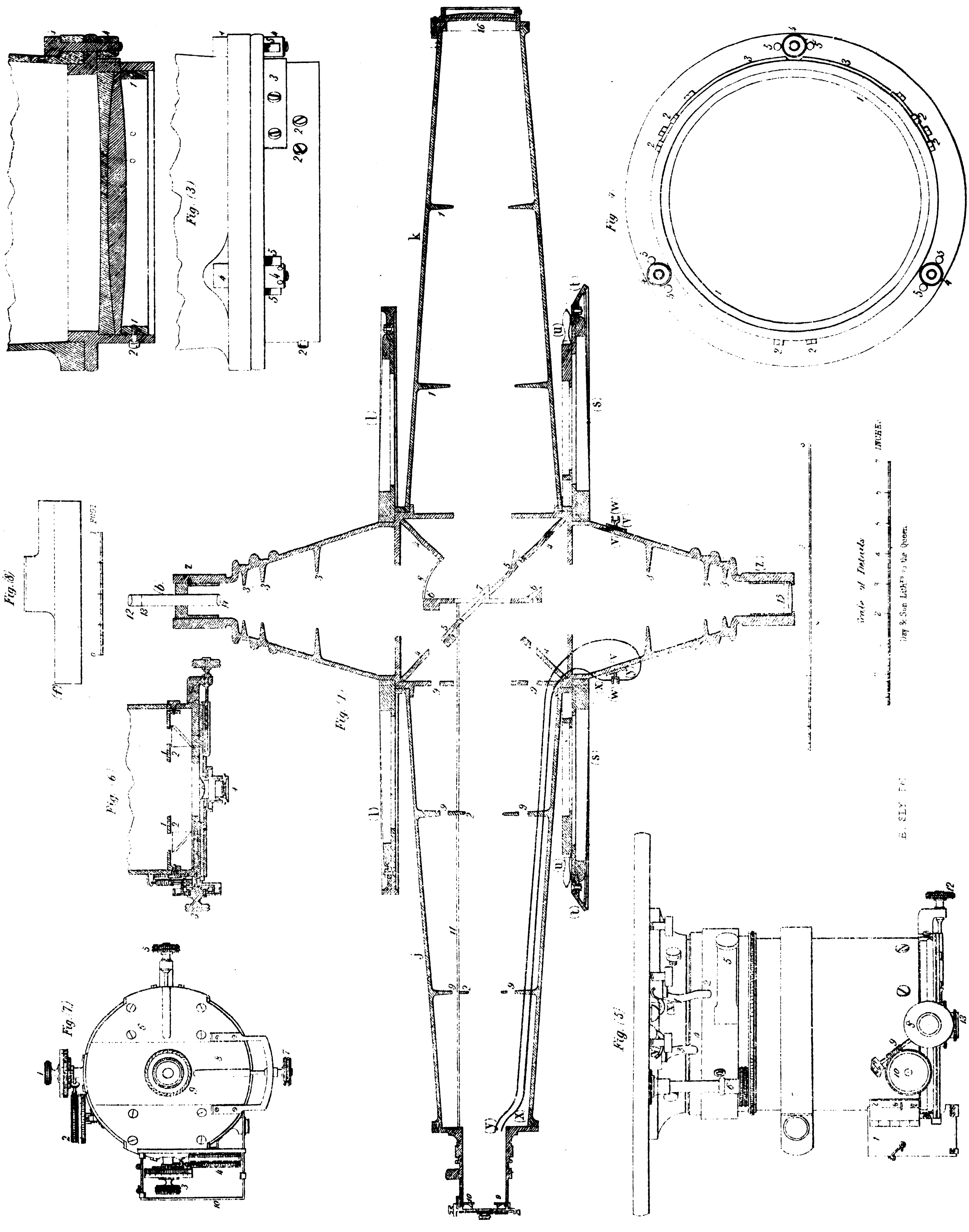

DETAILS (PRINCIPALLY OF THE TELESCOPE) OF THE TRANSIT-CIRCLE AT THE ROYAL OBSERVATORY, GREENWICH

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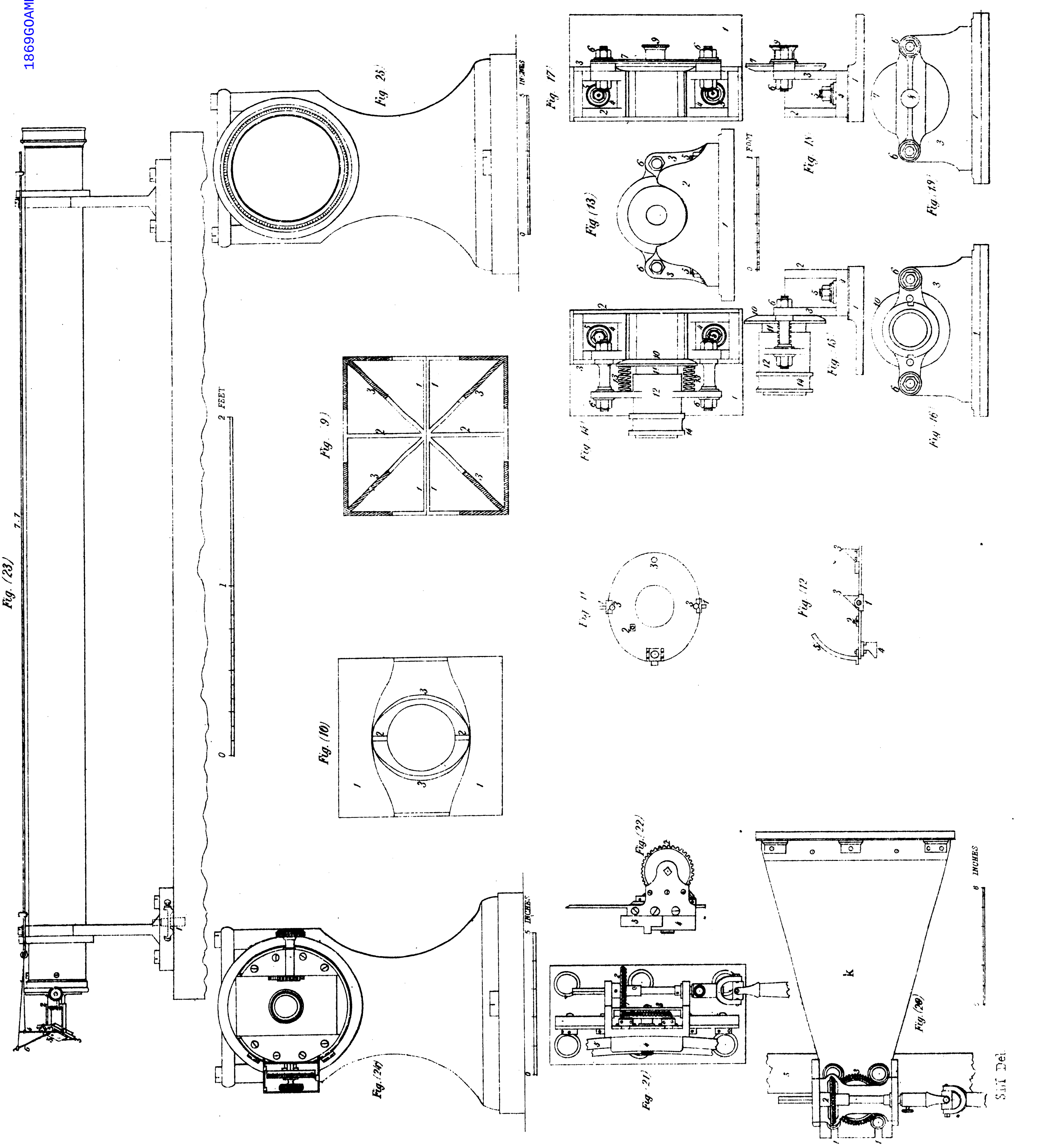

DETAILS OF THE TELESCOPE, SUPPORTS, CLAMPS, AND COLLIMATERS, OF THE TRANSIT-CIRCLE, AT THE ROYAL OBSERVATORY GREENWICH

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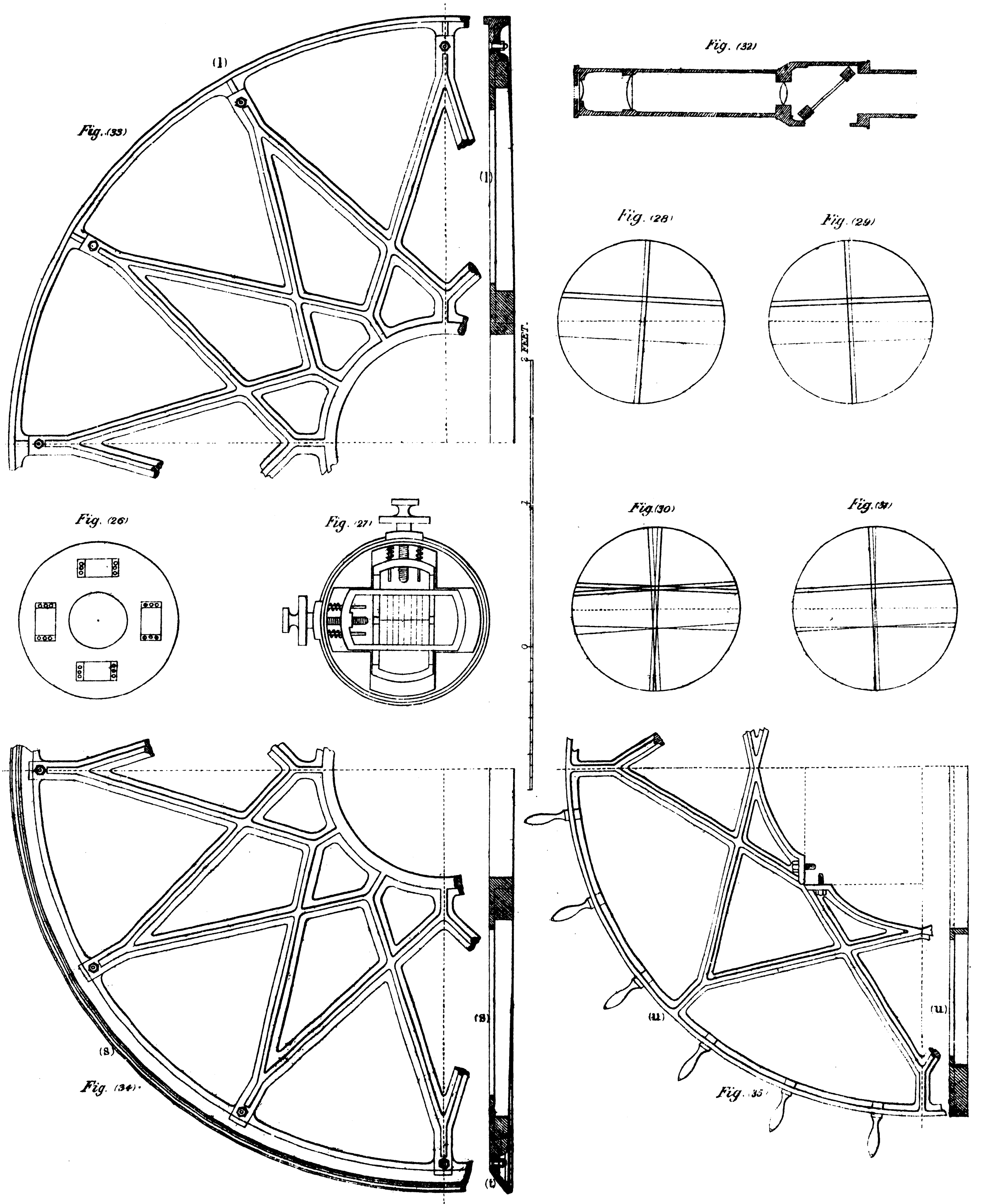

WIRE-PLATES, NADIR-EYEPIECE, AND CIRCLES, OF THE TRANSIT-CIRCLE AT THE ROYAL OBSERVATORY, GREENWICH.

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