APPENDIX III.

DESCRIPTION

OF

THE GREAT EQUATOREAL

AT THE

ROYAL OBSERVATORY, GREENWICH.

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The history of the construction and erection of this Equatoreal may be traced with great accuracy in the Annual Reports of the Astronomer Royal to the Board of Visitors of the Royal Observatory, commencing with that for 1856, June 7, or rather with an Address to the Board dated 1855, October 9, which is published with the Report. I there pointed out that, though it was much to be desired that observations with the Equatoreal should never to any important degree supersede those with the meridional instruments in the Royal Observatory, yet that we required an Equatoreal with a telescope far superior to those which we possessed, on a better mounting, and in a better position. In respect of the plan of mounting, I gave my reasons for preferring the English to the German form; and I indicated the locality in which I proposed to place the instrument, and which is the same as that actually adopted. For the accurate plan of this locality, I refer to the map accompanying the "Explanation of the Plan of Buildings and Grounds of the Royal Observatory, Greenwich, for 1863, August," published as Appendix II. to the Greenwich Observations, 1862.

The Board of Visitors warmly supported my views; and, on communication with the Lords Commissioners of the Admiralty, measures were taken for obtaining from Parliament the sanction to the expense.

In my Report of 1856, my contemplated plan of the instrument is given, precisely as it has been carried out. A few particulars are added in the Report of 1857.

It does not appear necessary to premise anything further, except that the framing of the polar axis was planned with reference to the focal length of the object-glass which Messrs. Merz first proposed to furnish. The focal length of the object-glass which they did subsequently furnish (an object-glass whose excellent definition well justifies the selection which they made) is somewhat shorter; and the mounting, prepared for the first object-glass, is therefore somewhat larger than is now actually necessary.

In the summer of 1860 the instrument was in a state fit for use.

Royal Observatory, Greenwich,
1869, *October* 19.

G. B. AIRY.

EXPLANATION OF THE PLATES.

PLATE I.

Figure **1** is an extract from the Map of the Royal Observatory, on a scale of 1 inch to 30 feet, showing only the elevated buildings which can in any way interfere with the view of objects from the Great Equatoreal.

1 is the South-east Dome, in which the Great Equatoreal is mounted. The extreme height of its dome is 50 feet; the height of the declination-axis of the Equatoreal, when used for south view, is 33 feet; above the floor of the Transit Room.

2 is the East Dome, containing the Sheepshanks' Equatoreal. Its top is 35 feet above the same floor.

3 is the South Dome, containing the Altazimuth. Its top is 33 feet 6 inches above the same floor.

4 is the Octagon Room of Flamsteed's original building. The height of its balustrade is 39 feet 3 inches; that of Robinson's Anemometer, 5, is 58 feet 7 inches; that of Osler's Anemometer, 6, is 61 feet 3 inches.

Figures **2, 3, 4, 5, 6, 7,** are all on the same scale of 1 inch to 20 feet, and the same numbers of reference apply to all. Figures **2, 3, 4,** are horizontal plans of the ground floor, the first floor (Chronometer Room), and the second floor (Equatoreal Room) of the South-east Dome. Figure **5** is a north-and-south vertical section, the view being directed to the west; figure **6** is an east-and-west section, the view directed to the south; and figure **7** an east-and-west section, the view directed to the north.

1 (in figure **2** only) is the boundary wall of the Observatory-enclosure, towards the north-east.

2, the passage to the Magnetic Ground. It is covered by a glass roof, as far as the entrance porch 5.

3, an iron tank for water (forming no part of the instrument).

4, the Record Room; only two stories high, and not interfering with the Equatoreal Room, and therefore shown only in figures **2** and **3.**

5, the entrance-porch.

6, the staircase, rising by one flight to the entrance of the Chronometer Room, and by a second flight to the entrance of the Equatoreal Room. The entrance to the lowest or ground-floor room passes round the west side of the foot of the staircase, in figures **2** and **5.**

7, 7, in figures **2, 3, 5,** and **7,** the north pier of the polar-axis of the Equatoreal. This pier has one solid foundation; then it rises in two piers, leaving a passage between them for entrance into the ground-floor room; then the two piers are united by a massive stone-crossing; then they rise separate, leaving a passage between them for entrance into the Chronometer Room; then they are covered by a massive stone, upon which the ironwork of 28, figures **4**, **5**, and **7**, is planted. This pier does not touch the walls or floors.

8, in figures **2**, **3**, **5**, and **6**, is the south pier of the polar-axis of the Equatoreal, built up without interruption through the lower room, and nearly through the Chronometer Room, where it receives the ironwork supporting the lower pivot, &c. of the polar-axis. It does not touch the walls or floors.

9, in figures **2**, **3**, **5**, is the central pillar for support of the radiating beams (now of iron) which carry the floors.

10, in figure **2**, is a thin partition of corrugated iron for separating off a small space used as an office for the business of chronometers.

11, in figures **2** and **5**, a stove. Its flue is led horizontally over the doorway of the lower room into the staircase space; then it rises to the next floor; it is then carried through the west wall of 6 in figure **3** to the angle of 4, where its final rise and discharge are made above the Record Room.

12, in figures **2** and **6**, the clock-work for moving the Equatoreal in right ascension, to be described hereafter, Plate VII., figures **47** to **52**.

13, in figure **2**, the supply pipe of water to the reaction-machine of the clock-work.

14, the discharge of water from the reaction-machine.

15, the gas-pipe entering below the floor of the lower room. It is then led to the north-east angle of the north pier 7, and is carried to the top of that pier and to the top of the iron frame 28 (figures **5** and **7**), where it enters the perforated pivot of the polar-axis, for communication with all parts of the Equatoreal frame, and ultimately for communication with the eyepiece of the telescope. Three branches are led from it; one round the east and south sides of the Chronometer Room to the chronometer-oven 22 (figures **3**, **5**, and **6**); one round the east and south sides of the Equatoreal Room to the lamp 23 which illuminates the microscope 16 for viewing the hour-circle (figures **24**, **25**, and **26**); and one under the floor of the Equatoreal Room to its center, where it drops into the Chronometer Room.

16, the place of entry of eight galvanic wires. Two of these are led to the south-west angle of the south pier, where they rise at 17 to the clock 37 (figure **26**), to make it beat simultaneously with the Transit-Clock. The remaining six wires rise at the north-east angle of the north pier; two of them, on arriving in the Chronometer Room, are led through the clocks 20, 20, 20, to make them beat simultaneously with the Normal Mean Solar Clock; two are continued upwards to the upper pivot of the polar-axis, and ultimately to the chronometer on the eye-end of the telescope, to make it beat simultaneously with the Transit-Clock; and two, following the same general course as the two last-mentioned, to the chronograph-touch-piece on the eye end. The wires are not shown in figures **3** and **4.**

Upon the floor, in figure **2,** are shown some square openings for descent into the basement; and in the angles of the walls are shown some cabinets and shelves.

18, in figures **3** and **5,** a stove. Its flue is led out in the same manner as that of 11, and ultimately has its discharge above the Record Room.

19, the vertical box through which the spindle of the clock-movement rises, and in which is the anti-friction apparatus, figure **53.**

20, 20, 20, three clocks regulated by the galvanic currents to coincide with the Normal Mean Solar Clock. Upon the central pillar 9 there is also a clock unconnected with the galvanic system.

21, the gas-pipe conveying gas to heat the chronometer-oven 22.

22, in figures **3, 5,** and **6,** the chronometer-oven. Above its upper part are the cords and counterpoises for assisting the raising of its upper lids. Near the floor are small doors for giving access to its gas-burners which heat the interior space.

(22), (22), in figures **3, 5, 6, 7,** chronometer-tables.

23, the flue from the heating-chamber of the chronometer-oven, led into the flue of the stove 18.

24, in figures **3, 4, 5, 6,** a box made of slate, suspended from the floor of the Equatoreal Room, and hanging into the Chronometer Room, into which the observer can descend for the purpose of reading the lower part of the hour-circle of the Equatoreal.

25, horizontal section of the vertical rod 12 of Plate VII., by which the observer in the Equatoreal Room can regulate the flow of water to the clock-movement 12 in figure **2.**

26, in figure **4,** the opening in the floor of the Equatoreal Room, through which the vertical spindle rises from the clock-work, and, by action of its endless worm, drives the wheel (in the same opening 26) of the spindle which carries the worm that drives the hour-circle of the Equatoreal.

27, in figures **4** and **5,** the iron frame supporting the lower pivot of the polar-axis of the Equatoreal.

28, 28, in figures **4, 5, 7,** the two upright portions of the iron stand supporting the upper pivot of the polar-axis of the Equatoreal.

29, the plate with central pivot on which the great frame carrying the observing-chair turns in azimuth.

30, the iron rail on which one pair of the wheels of the great frame run.

31, the iron rail on which the other pair of the wheels of the great frame run.

32, in figures **4, 5,** and **6,** a wooden circle in the plane of the equator, for supporting an observing-chair, which may be passed through the Equatoreal frame in observation of objects very near the pole, without touching the polar-axis of the Equatoreal.

33, in figures **4, 5, 6,** a set of steps in theatre form, affording a seat to the observer in positions which cannot be reached by the great frame of the observing chair.

34, in figures **5, 6, 7,** the revolving dome (all machinery is omitted).

Arches, not represented in figure **4,** are carried over the angles of the octagon, converting the octagon into a polygon of sixteen sides, for better support of the circular ring on which the dome revolves.

PLATE II.

Figures **8, 9, 10, 11, 12,** relating to the general construction of the revolving dome, are on the scale of 1 inch to 15 feet. Figures **13** and **14,** showing the motion of the dome on its balls, are on the scale of $\frac{1}{10}$. Figures **15** and **15*,** showing the action of the machinery by which the dome is held fast (for safety), are on the scale of 1 inch to 3 feet; and figures **16** and **17,** showing the mechanism by which the dome is made to revolve, are on the same scale.

The same numbers of reference apply to all the figures of Plate II.

1, in figure **8,** and in the section enclosed in it, is the gutter for receiving the rain-drippings.

2, in figures **8, 13, 14, 15, 15*, 17,** is the iron concave channel upon the wall, in which run the balls that support the inverted iron channel of the moveable dome.

3, in figures **8, 9, 13, 14, 15, 15*, 16, 17,** is the rack-work of teeth, pointing upwards, in the same cast of iron with 2, in which acts the pinion 19 of figure **17,** attached to the dome.

4, in figures **9, 13, 14, 15, 15*,** is the circular curb which forms the base of the dome. Upon the circular curb, which is made of three thicknesses of wood, are planted the uprights, of which the feet appear in figure **9,** and which are seen in figures **11** and **12**; portions also being seen in **15, 15*, 16, 17.**

At 5, in figures **9** and **10,** there are two strong uprights at a greater separation (3 feet clear) than the others. They support the ends of the principal beams carrying the flat roof. The machinery for giving circular movement to the dome is attached to them. It will be seen in figure **10** that this is the side opposite to the vertical opening of the dome; so that the person managing the mechanism for rotating the dome always sees the part of the sky to which the telescope is to be directed.

At 6 are similar uprights at the same separation. They carry the opposite ends of the principal beams, and the vertical shutter, and the machinery for opening and closing both the vertical and the horizontal shutters.

At 7, 7, are similar uprights, merely for carrying the ends of the principal beams of the second order.

At 8, 8, 8, 8, in figure **9**, are the four points of attachment of the apparatus, described in figures **15** and **15***, for immoveably fixing the dome.

9, in figure **10**, is the roof opening, closed by a horizontal shutter. It extends from the circumference of the dome to a point about 1 ft. 6 ins. beyond the center.

10 is the large toothed-arc (to be explained hereafter, figures **22** and **23**) by which the horizontal shutter is moved.

Figures **11** and **12** are perspective views of the dome-frame in different stages of its construction. In figure **11** are shown the lower wood-curb with the uprights planted on it; and the upper ring, cut through for the observation opening; and the two principal beams running quite across; and the principal beams of the second order; and the other framing as in figure **10**. In figure **12** are shown the interwoven diagonals of hooping-iron, which are on the outside of the uprights; and the sloping roof raised above the flat framing of figure **10**; and the depressed space in which the shutter of the roof-opening turns. On the outside of the hooping-iron the cylinder of the dome is completely covered with planks of very thin wood, bent round horizontally, and fixed to the uprights; and the whole is covered externally with sheets of zinc.

Figures **13** and **14** are sections of the wall-curb, the dome-curb, and the balls on which the dome rolls, at two parts of the dome.

11 is the iron-curb of the dome, through the greater part of its circumference, exactly corresponding in curvature to 2 inverted. The radius of curvature of each is about $4\frac{1}{2}$ inches.

12 is the iron-curb for the length of 12 feet, its central part being under the opening 6. It will be remarked that, from the interruption of the upper ring of the dome, and of all the diagonal-ties of hooping-iron, as well as from the considerable weight carried by the principal uprights, the dome is weaker in that part than in any other; and it was found liable to change its form according as that part of the curb was or was not supported on an iron ball. To remedy this, the strong iron-curb shown in 12 was affixed. The curvature of its channel is the same as that of 11.

13 is one of the balls, 6 inches in diameter. If the dome were perfectly rigid, it might move properly upon three balls; but, viewing its liability to change its form (in some measure), and to strain its connexions, it appeared best to adopt the rule of placing under it as many balls as would be constantly in action. The number adopted is six.

Figures **15** and **15*** show the mechanism for fixing the dome firmly, to prevent disturbance by the wind.

14 is a lever whose center of motion is carried by a small internal projection from the dome curb 4. Its upper end is inclined to its general length, and in that inclined part is a slot or longitudinal opening. Its lower point, when it projects inwards into the dome, presses against the teeth of the rack-work 3 In figure **15** it is represented as pressing the teeth; in figure **15*** it does not touch the teeth.

15 is another lever, turning upon a center of motion, which is fixed to the side of an upright, and carrying a pin which slides in the slot of the lever 14.

16 and 17 are two rings upon a chain, of which one end acts immediately upon the end of 15 to pull it down, and the other end, led over a pulley, acts on the same end of 15 to pull it up. If, as in figure **15,** a weight be hung on 16, it pulls 15 down, and the action of its pin, sliding in the slot of 14, causes the lower end of 14 to press strongly against the teeth of the rack-work. When the four systems, at the places represented by 8, 8, 8, 8, in figure **9,** are thus in action, the dome is fixed firmly, and does not move in the heaviest gales. If, as in figure **15*,** the weight be hung on 17, the lower point of 14 is withdrawn from the rack-work; and when the four systems are thus in action, the dome is perfectly free to move. The transfer of the weight from the ring 16 to 17, or *vice versâ*, is very easily effected by the use of two hooks fixed in the weight.

Figures **16** and **17** represent the apparatus by which rotatory motion is given to the dome. It will be seen, by comparing the reference 5 in figure **16** with 5 in figure **9,** that it is attached to that side of the dome which is opposite to the vertical shutter.

18, 18, 18, 18, is the frame, of wrought iron, which is attached to the dome curb, to two principal uprights, and to two neighbouring uprights of the dome.

19, in figure **17,** is the pinion carried by the frame 18, and working in the rack-work 3; by the revolution of this pinion, rotation is given to the dome.

20 is a bevelled-wheel upon the same axis with 19, but connected with 19 only by a sliding clutch.

21 is a bevelled-pinion upon a vertical axis carried by 18, working in 20.

22 is a bevelled-wheel on the lower end of the same vertical axis.

23 is a bevelled-pinion on a horizontal axis, driven by the winch 24.

25 is another bevelled-wheel upon the same axis.

26 is a pinion, which can be brought at pleasure to work in 25, and by which the observer in his observing-chair, having applied a long handle to the axis of 26, can give motion to the dome.

27 is a small catch, which can be dropped into the teeth of 25, to prevent any accidental disturbance of the wheel-work.

28 is a handle by which the clutch, that connects 19 with 20, can be moved at pleasure either to effect that connexion or to destroy it. If, by means of 28, 19 and 20 be disconnected, the dome may be moved by force applied to it, but cannot be moved by the winch 24. If 19 and 20 be connected, the dome can be made to rotate only by turning the winch 24. The person who turns the winch must walk on the floor, following the motion of the dome.

PLATE III.

This plate is appropriated to the mechanism for opening and closing the vertical shutter in the wall of the dome and the horizontal shutter in its roof. The machinery of the two is somewhat intermingled; but figures **18, 19, 20,** and **21,** apply principally to the vertical shutter, and figures **22** and **23** to the horizontal shutter. The reference-numbers are, as far as 13 (excepting 1 only), the same as in Plate II.; the numbers 5, 7, 8, 11, being omitted. All are on the scale of 1 inch to 3 feet.

Figure **18** is a view, from the inside, of the mixed machinery, to a small height.

Figure **19** is a cross-section of the same.

Figure **20** is a horizontal plan of the machinery of the vertical shutter or wall shutter when the shutter is closed.

Figure **21** is a horizontal plan of the same, when the shutter is open.

1, in figures **18** and **19,** is the wooden ring or curb upon the wall of the dome.

2, in figures **18** and **19,** is the iron channel in which the balls run. It is hidden in figures **20** and **21** by the curb of the dome.

3, in figures **18, 19, 20, 21,** is the circle racked with teeth. The teeth are omitted here, to avoid confusion.

4, in all the figures, is the wooden curb of the dome.

6 is the opening between two principal uprights, which opening may be closed by the vertical shutter.

12, in figure **19,** is the iron channel and curb of the dome. It will be remarked that this is the part of the dome which has required strengthening by an iron curb of great depth.

13, in figures **18** and **19,** is one of the balls on which the dome runs.

14, in figures **18** and **19**, the frame attached to the dome, which carries the lower wheel machinery of the shutters.

15, the winch, at a convenient height above the dome floor, for opening and closing the vertical shutter.

16, a bevelled wheel attached to the winch.

17, a catch which drops into the teeth of 16, to prevent accidental disturbance.

18, a bevelled-wheel, on a vertical spindle, in which 17 works.

19, a toothed-wheel upon the same spindle, which works in the large broken wheel 20 and 21.

20 and 21, the two parts of the broken-toothed-wheel which acts immediately upon the shutter 22. 20 is firmly fixed to 22. 21 is jointed to 20, in such a manner that it can bend towards the center of 20 so as to form a complete circle, but no further; but it can bend from the center of 20 as far as may be required.

22 is the vertical shutter. In figure **20** it closes up the opening 6; in figure **21** it is thrown back so as to touch the external covering of the dome; an important arrangement, because it leaves no surface on which the wind can act to give rotatory motion to the dome.

23 is a pin projecting downwards from the end of 21.

24, 24, are two narrow iron plates forming a guide or channel in which 21 can slide.

The nature of the movement by which the shutter is closed, or by which the mechanism is changed from the state of figure **21** to that of figure **20**, is the following. By means of the winch 15, acting through 16 and 18, motion is given to 19. The joint which connects 21 with 20 is so firm, that 21 cannot escape from the action of 19; and the pin 23 is carried gradually towards the channel between 24 and 24. When the joint of 20—21 comes under 19, the pin 23 is entering the channel. 19 now acts upon the firm arc 20, and 21 is free to be guided by its pin 23 running in 24, 24. Immediately, it begins to bend backwards, and finally the toothed wheel assumes the form shown in figure **20**.

25, in figure **18**, is the winch; 26 the first bevelled-wheel; 27 the safety-catch; 28 the second bevelled-wheel; and 29 the long spindle for moving the horizontal shutter of the roof. 29 is also shown in figure **22**; and the section of 29 in figures **20** and **21**.

Figure **22** is a vertical section passing through the openings 6 and 9; and figure **23** is a vertical section transverse to that of figure **22**, showing the mechanism for moving the roof-shutter.

30 is a bevelled-wheel on the long vertical spindle 29, shown in figure **18**.

31 is a bevelled-wheel in which it works; it drives, by a long spindle, the small wheel 32, hidden in figure **22,** but shown in figure **23.**

10 is the large arc in which 32 works; it is firmly attached to the shutter 33.

33 is the shutter, which does not (like 22) turn through 180°, but through perhaps 140°. As the shutter is sunk in a deep hollow of the roof, it is not exposed to the wind, and it is not visible to spectators below. There was, therefore, no object to be attained by making it turn through 180°, and much complexity of machinery was avoided by abandoning that condition.

34 is the counterpoise to the weight of the shutter.

The end of the horizontal shutter covers the vertical shutter, and either shutter can be opened or shut without regard to the other.

PLATE IV.

This plate contains the figures explanatory of the upper or north end and the lower or south end of the polar-axis-frame. All are on the scale of 1 inch to 2 feet.

Figures **24, 25, 26, 27,** relate exclusively to the lower end, and figure **24*** to a small apparatus near it. The view in figure **24** is vertically downwards; that in figure **25** is in the direction parallel to the earth's axis. Figures **28, 29, 30,** relate exclusively to the upper end.

1 is the iron base-plate planted upon the great southern pier. A portion of the pier is shown in figure **26.**

2, 2, 2, 2, 2, are holes into which liquid cement was poured, to insure a firm bearing of the iron upon the pier.

3, 3, is the higher part of the iron-work, its upper surface being parallel to the celestial equator.

4 is the moveable plate which carries the immediate bearing of the lower polar-axis pivot.

5, 5, 5, 5, are adjustment-screws for 4.

6, 6, 6, 6, are clamping-screws for 4.

7 is the socket in which the lower pivot turns; the pivot is not fitted to 7.

8 is a moveable block in 7, containing the steel surface on which the polar-axis actually takes its endwise bearing.

9, a screw for endwise-adjustment.

10, a clamping-screw for fixing 8.

11, 11, the iron pivot of the lower end of the frame of the polar-axis, cast in one piece with the lower end of the polar-frame. In figure **24,** only so much of the pivot is shown as projects below the frame of the equatoreal-circle or hour-circle; in figure **26** it is shown as projecting through the equatoreal-circle to the point where it unites with the rays of the lower end-frame.

12, 12, are the supports of the axes of the anti-friction wheels.

13, 13, are the anti-friction wheels. These take the entire bearing of the lower pivot of the polar-axis in the equatoreal direction.

14 is the racked edge of the great equatoreal-circle. It is cut with 720 teeth, in which the endless screw 33 acts.

15 is a graduated edge of the equatoreal-circle, divided to time.

16 is a microscope, carried by a firm pillar (part of 4), for viewing the graduations of 15. When the equatoreal-circle has been properly adjusted, and the clock-work (to be hereafter described) is moving it with the proper speed, the graduation under view of 16 always reads true Sidereal Time of the moment.

17 is another graduated flat band of the equatoreal-circle, divided to time.

18, 18, are two microscopes carried by the lower end-frame of polar axis, for viewing the graduations of 17. When all adjustments are correct, the readings under 18, 18, represent, one, the right-ascension, the other, the right-ascension $+12^{h}$., of the object viewed with the telescope.

19 is the cast-iron lower end frame of the polar-axis.

20, 20, 20, 20, 20, 20, are the ends of the pillars of the frame parallel to the earth's axis, to be hereafter described.

21, 21, are clamp-screws for fixing the equatoreal-circle to the slow-motion-screw (not represented in these plans) which is connected with the lower end-frame of the polar-axis. When this fixation is made, the polar-axis receives the same angular movement as the equatoreal-circle, which movement corresponds exactly with the apparent rotation of the celestial sphere. By means of the slow-motion-screw, a small alteration with respect to the heavens can be given to the position of the telescope without disturbing any connexions.

22, 22, are clamps by which the equatoreal-circle and the lower end-frame of the polar-axis can be firmly connected without the intermediation of the slow-motion-screw. When either of these clamps is put in action, the polar-axis rotates with the same angular velocity as the equatoreal-circle, but its position cannot be altered by the slow-motion screw.

22* is a clamp to be used only when the clock-work is not in action. It fixes the equatoreal-circle rigidly; and therefore, when 22 is also put in action, the polar-frame is fixed rigidly. (The equatoreal-circle may be held, but less firmly, by forcing the worm 33, not revolving, into the teeth of 14; and the lower end-frame may be connected with the equatoreal-circle, but less firmly, by the slow-motion-screw and 21.) The clamps 22 and 22* are used only when transits in right-ascension are required.

25 is the vertical spindle from the clock-work 12 in Plate I., to be fully described hereafter. It revolves in one quarter of a second of sidereal time.

26 is the worm or endless screw on 25, working in 27.

27 is a racked wheel of 480 teeth, which by the clock-work, acting through 26, is made to revolve in 2^m. of sidereal time.

28, 28, are the two fulcra, and 29 the spindle, of the gearing-lever by which the worm 26 is forced into the teeth of 27.

30, figure **27**, is the long arm of the gearing-lever.

31, a long rod and handle by which a person viewing the microscope 16 can manage the gearing-lever. By pulling 31, the frame carrying 25 is pulled, and 26 is detached from 27. On relaxing the pull on 31, 26 is pressed to 27 by a spring with definite pressure.

32, the axis of the wheel 27, carrying the great worm 33, which acts in the rack-work 14 of the equatoreal-circle. The uniformity of the spiral of 33 was very carefully examined.

34, 34, the two fulcra of the gearing-lever by which the worm 33 is forced into the teeth of 14.

35 is the long arm of the gearing-lever.

36, a long rod and handle by which a person viewing the microscope 16 can manage the gearing-lever. By pulling 36, the frame carrying 32 is pulled, and 33 is detached from 14. On relaxing the pull upon 36, 33 is pressed to 14 by a definite spring-pressure.

37 is a small sidereal clock, sympathetic with the Transit-Clock, of which the regulation is to be described hereafter. It has a half-seconds pendulum, but its escapement is analogous to that of a chronometer, and it therefore beats at every second.

38, in figures **24** and **24***, a winch for regulating the water-tap of the clock-work below.

39, the quadrant on which it acts.

40, the rod communicating with the tap-lever of the clock-work 12 in Plate I.

The remaining figures of this Plate, figures **28, 29, 30**, relate to the upper end-frame of the polar-axis.

41, 41, in figures **28** and **29**, is the upper inclined part of the iron stand 28, 28, in figures **4, 5, 7**, of Plate I., supporting the pivot of the upper end-frame of the polar-axis.

42 is the iron frame fixed on 41, which carries the anti-friction wheels.

43, 43, are the two anti-friction wheels, upon which rests the pivot of the upper end-frame, and which determine the position of the pivot.

44, in figure **29**, is the pivot. It is omitted in figure **28**.

45 is the mushroom-head of the pivot, which hangs in some measure upon 42, and prevents endwise-slip between the pivot and its support.

46 is the upper end frame of the polar-axis. Figure **30** shows that one part of the oval is omitted; it will be seen hereafter that this omission permits the observation of objects northward to the celestial pole.

47, 47, 47, 47, 47, 47, the ends of the pillars of the polar-axis.

48, 48, 48, is the gas-pipe, by which gas is conveyed to the polar-frame and to the telescope. It is led up along one of the arms 41, then to a point in the prolongation of the central axis of the pivot, where it is connected by a rotatory gas-pipe-joint with the gas-pipe that passes through the central perforation of the pivot 44; after which it is led along one of the long radii of the upper end-frame, and descends along one of the long pillars of the polar-frame. The part, after emerging from the central perforation of 44, is shown by dotted lines in figure **30**; but in figure **29** it is directed to the eye, and appears only as section of the pipe.

49 is a system of four springs for galvanic communication, each on a separate insulated mounting, which are connected with the four galvanic wires mentioned in the last part of the description of 16, Plate I.

50 is a system of four corresponding rings on the pivot, each of which is touched by one of the springs of 49, and each of which is on an insulated mounting. To these four rings, four wires are soldered, which are led down a pillar of the polar frame to insulated springs touching insulated rings upon the declination-axis, whence they are led to the eyepiece; two for control of a chronometer, and two to the touch-apparatus for chronographic registration.

Several oiling-pipes and oil-cups are omitted in the plans.

PLATE V.

This plate contains details of the polar-axis, the telescope-tube, and the mode of mounting the tube on the polar-axis. The scale of figures **31, 32, 33, 33*, 34,** is 1 inch to 6 feet; that of figures **35** and **36** is 1 inch to 2 feet; and that of figure **37** is $\frac{1}{30}$.

Figure **31** relates principally to the connexion of two polar-pillars near the minor-axes of figures **25** and **30**; other connexions of pillars being shown lightly.

1, in figure **31,** is the upper pivot of the polar-axis, with its mushroom-head as in 45 of Plate IV.; it is shown here in section.

2 is the lower pivot, shown in section; the lower part of it corresponds to 11 of Plate IV. Its great length is necessary for carrying the equatoreal-circle 14 of Plate IV.

3, 3, in all the large figures, are polar-pillars, corresponding to the four points of attachment nearest to the minor-axis of the end-frames in figures **25** and **30.**

4, in all the large figures, is a polar-pillar, corresponding to a point of attachment at the end of the major-axis of figures **25** and **30.** One pillar 4 with the two neighbouring pillars 3 constitute one prismatic side of the polar-axis.

The polar-pillars are iron tubes, procurable in ordinary commerce. When the telescope was finally mounted, holes were drilled into the sides of two of the tubes 3, 3, and leaden shot were poured in, in the proper quantity for putting the frame in equilibrium.

5, 5, &c., are diagonal-rods. Their ends are attached to bands fixed on the polar-pillars.

6, 6, &c., are points at which each diagonal-rod is divided, and is united by cylinders which embrace the two segments with internal screw-threads, one cut with a right-handed screw, and one with a left-handed screw. By turning these cylinders, the length of the diagonal-rod can be increased or diminished.

7, 7, &c., rods parallel to the end-frames, which thrust the bands apart. Each of these rods has, at 8, 8, &c., a screw at one end, and a thrusting-point at the other end, and the rod can be virtually lengthened or shortened by turning it. It will be remarked that the rods 5 and 7 are part of the framing which connects 3 and 3 only (not 3 and 4).

9 is a handle for giving slow motion in right-ascension to the polar-frame. It is connected at 10, by bevelled-gearing admitting of universal motion, with the spindle 11, which is connected at the bottom with a spindle that acts upon the slow-motion screw of 21 in figure **25.**

12 is a bar for carrying a sliding hook in which 9 may be lodged for convenience.

Figure **32** relates only to the connexion of one of the pillars 3 with one of the pillars 4. It will be seen that the space between them is divided into four parallelograms; while that between 3 and 3 is divided into three parallelograms.

13 and 14 correspond in all respects to 5 and 7.

In figures **33, 34, 35, 36, 37,**

15, 16, 17, represent the support of each pivot of the declination-axis. 15 is the actual bracket, very firmly clamped to the pillar 4. 16 is a very strong bar, connecting the base of the bracket with pillar 3; and 17 a lighter bar, connecting the point of the bracket with 3. 15, 16, 17, constitute a triangle in one piece.

It will be seen from the form of these, especially in figure **37,** that the declination-axis crosses the polar-frame, not in its centre, or in the line of the major-axis of the end-frames, but in advance of that major-axis. By this arrangement, taken in connexion with the obliteration of a part of the circumference of the upper polar frame, as shown in figure **30**, it will be seen that the telescope can be directed to any degree of north-declination up to the pole.

18, 18, are the ends of the pivots of the declination-axis.

19, a winch, connected with a screw and stirrup by which the pivot can be lifted out of its bearing.

20, 20, the conical axes of the telescope, similar to those of a transit-instrument.

21, the perforated iron case in which the telescope is inserted.

22, the telescope-tube. It consists of four planks of mahogany, forming a square tube; towards both ends the angles are cut off by inclined cuts, by which operation the square is reduced to an octagon, well adapted to the reception of the brass-work of the object-glass and eyepiece. There are several diaphragms in the tube, by which it is made very firm.

23, the clamping-circle. On the side next the right-hand in figure **36**, it is immediately attached to a pillar 3 by two clamps; on the side next the left hand, it is attached to another pillar 3 by a projecting piece of iron.

24, the declination-clamp, carried by the iron case 21.

25, the rod of the screw for pinching the clamp, manipulated at the eye end of the telescope. Beneath it is concealed, in the view figure **37**, another rod, called 25* in figure **39**, for acting on the slow-motion of the clamp.

26, the graduated circle, attached to the case 21.

27, 27, the microscope for viewing the graduations. The band carrying the graduations is on an internal conical surface of 26, perpendicular to the direction of 27.

28, 28, the illuminating-tubes. The light of the gas-lamps 29, 29, enters these tubes; it is received on an inclined transparent plate of glass in each (whose transparency permits microscopic view), and is reflected down through the microscope to the graduated band of 26, whence it is reflected upwards to the eye at the microscope. The gas-lamps are on jointed pipes, and are counterpoised.

30, the gas-pipe which descends from 48 in figure **29**.

31, 31, the feeders of the gas-lamps 29, 29.

32, the pipe which carries gas to the rotatory-gas-joint in the pivot of the declination-axis, whence it is carried to the burner 33 at the eye-piece of the telescope.

34, a radial-arm on the side of the telescope-tube, turning upon a pin at 35, carrying a graduation at 36, and a pin with mushroom-head at 37.

38, in figures **33** and **33***, sliding rods, with graduations on the slider, for connecting the pin 37 with a pin on a pillar 3, the place of which is seen in figures **31** and **33.** When 36 is near the middle of its graduation, the graduation upon 38 exhibits very approximately the north-polar-distance of the object observed. This apparatus is convenient for directing the telescope to any given north-polar-distance; it is not used for clamping the telescope, or for reading the N.P.D. accurately. There is a pin upon the other pillar 3 of figure **31**; and upon some of the sliding rods there are double graduations, adapted to every polar distance.

39, a cable of four galvanic wires, led down from the four insulated rings 50 in figure **29.**

40, four insulated springs with which these wires are connected.

41, four insulated rings touched by the springs 40. To the rings 41 wires are soldered, which are led to the eye-end of the telescope.

42, 42, two of these wires, constantly completing a circuit at the eye-end. They pass through a chronometer 43, whose rate they regulate; through a seconds-beater 44, which is used merely to notify audibly the seconds of time; and through a terminal-plate 45, which is convenient for change of connexions. The dial plate of 43 fronts the observer at the eye-glass of the telescope.

46, two of the wires, of which one leads to an insulated ring 47, and the other leads to an insulated touch-piece. On pressing this touch-piece with the finger, a galvanic circuit is completed, by which a puncture is impressed on the barrel of the chronograph of the Observatory.

48, a small winch for changing the inclination of the illuminating-reflector. The illuminating-light from 33, which is on jointed pipes, enters at a small window, seen below 48.

49, a small counterpoise for the telescope, used only when the weight of the radial-bar is supported by one of the rods 38.

50, one of two rods leading to the object-end of the telescope, which act there upon two screws that work in the cell of the object-glass, and, in conjunction with a third screw for which no movement is required, determine the inclination of the object-glass to the axis of the telescope. By means of these two rods, the observer, while viewing a star, can adjust the inclination of the object-glass, so as to make the image of the star the best possible.

PLATE VI.

This plate contains the termination of the plans of the declination-axis and the telescope; the regulating portion of the sidereal clock which is mounted on the fixed plate supporting the south pivot, and that of the chronometer at the eye-end of the telescope; and the observing chairs. The reference-numbers are continued in sequence from Plate V.

Figures **38** and **39** are perspective views, on a scale of 1 inch to 2 feet nearly, of the declination-axis with declination-circle, and of the telescope; and figure **39*** is a plan of the mounting of the object-glass, $12\frac{3}{4}$ inches clear aperture. The reference-numbers, with the exception of 25* and 51, are all explained in the description of Plate V.

18, the form of the declination-pivots is shown.

25*, the rod for acting on the slow-motion of the declination-clamp.

50, three screws for holding the object-glass-frame; it is not, however, necessary to attach rods to more than two, as is shown in figure **39.**

51 is the finder.

Figure **40** represents, in half-size, the regulating part of the sidereal clock 37 in figures **24** and **26.** It is to be remarked that this clock is half-seconds, in the ordinary sense, and therefore the homologous movements of the pendulum occur at intervals of whole seconds. At these intervals the escape-wheel of the Transit-Clock makes contact of galvanic springs which complete a galvanic circuit. All that is wanted for regulation of the clock 37 to the same rate as the Transit-Clock is, that the galvanic currents thus produced shall act on the pendulum of the clock 37.

52 is the pendulum-cistern of the clock 37.

53 is a steel-magnet attached to the pendulum. The position of the poles of the magnet is indifferent; if one pole enters the coil 54, the clock 37 will always be a little in advance of the Transit-Clock; if the other pole, 37 will always be a little in retard of the Transit-Clock.

54 is a galvanic-coil formed by the wires 42, which are led from the springs of the Transit-Clock.

Figure **41** represents, in full size, the regulating part of the chronometer 43 in figures **37** and **39.**

55, 55, is the chronometer-balance.

56, the balance-spring.

57, 58, two magnets attached to the balance-axis, with their poles in opposite positions. They are therefore sensibly astatic as regards the magnetic action of the earth; but the effects of the coil 42* upon the needle 57 swinging within it, and upon 58 swinging outside, are of the same kind.

42*, a coil formed by the wire 42. The coil and the needles are in all respects similar to those of the ordinary needle-telegraph.

The balance 55 completes two double vibrations in one second of time. Therefore, at every second, its movements are homologous; and, receiving an impulse at every second from the galvanic action through the wire 42, it is maintained with the same rate as the Transit-Clock. This arrangement was suggested and successfully carried out by Mr. William Ellis, Assistant of the Royal Observatory.

It will be remarked that the same reference-number 42 is attached to the wire in figure **40**, where the coil is supported by an immoveable pillar, and to the wire in figure **41**, where the coil is carried by the moveable eye-end of the telescope. It will be seen from the following explanation that this identity of reference is correct. A wire 42 from one spring of the escape-wheel of the Transit-Clock enters the lowest room of the building at 16 in figure **2**, and rises at the south-west angle of the south pier to the clock 37 in figure **26**, and to the coil 54 in figure **40**; it then descends by the same course to 16 in figure **2**, and is led to a terminal-closet in the Transit-Circle Room, where it is joined to another wire, still called (in these plans) 42, which re-enters the building at 16 in figure **2**, is carried to the north-east angle of the north pier, rises to one of the springs 49 in figure **29**, communicates with a ring 50, whence a wire, here still called 42, is led to a spring 40 in figure **37**, which communicates with a ring 41, whence a wire, still called 42, is led to the coil 42*, in figure **41**, from which the galvanic communication returns by a parallel course to the battery and to the other spring of the escape-wheel of the Transit-Clock. When the two springs of the escape-wheel are brought into contact, the battery-current passes at the same instant through the two coils, 54 in figure **40**, and 42* in figure **41**.

Figures **42**, **43**, **44**, **45**, show the construction of the principal observing-chair, on a scale of 1 inch to 5 feet.

59 is the great chair-frame.

60, the fixed pin in the floor of the room, round which the chair-frame turns in azimuth. It is marked 29 in figure **4**.

61, 62, the larger wheels, running upon the iron rail 30 in figure **4**. The inside of 61 is racked with teeth (the breadth of the circular rim being made greater than is simply required for the radial spokes).

63, 63, the smaller wheels, running upon the iron rail 31 in figure **4**.

64, a pinion which can work in the inside of 61. In figure **45** it is disengaged; in figure **44** it is engaged and hidden.

65, a bevelled-wheel on the same axis with 64.

66, a bevelled-pinion working in 65. In figure **45** they are disengaged; in figure **44** they are engaged.

67, a spindle with hook's-joint and sliding-tube, worked by a winch 68 which is carried by the sliding observing-chair, and is always within reach of the observer's hand.

When 64 is disengaged from 61, the chair-frame can be pushed round by hand.

When 64 is engaged with 61, the chair frame is moved with great facility by means of the winch 68.

69, 69, the frame of the sliding-chair. It is a rectangular frame; at its upper and lower ends are iron pins projecting horizontally from both sides. These pins slide in quadrantal grooves in the sides of the great chair frame, shown by the dotted curves 69* in figures **43** and **44**. An upper and a lower pin on one side run in the groove 69* of figure **43**, and an upper and a lower pin on the other side in the groove 69* of figure **44**. Upon the frame will be seen a seat, a foot-board, and a back-board 77.

70, a winch acting on a pinion 71 and toothed-wheel 72 upon a windlass, by which a cord 73 is drawn, that passes over a pulley above and is attached to a spindle 74 of the sliding-frame; and thus is used to raise or lower the whole sliding-frame. Upon the axis of 72 is a ratchet in which a click drops, to prevent the sliding-frame from slipping down.

75, a winch for turning an endless-screw 76, which acts in a racked-wheel upon the spindle 74. By turning this spindle, the suspending rope 73 is shortened or lengthened, and thus the observer in the chair, by manipulating the winch 75, can raise or lower the chair to a considerable extent.

77, the chair-back, moveable by a hinge connecting the bottom of the chair-back with the chair-frame, and having a racked-arc of which that hinge is the center.

78, a winch with endless-screw 79 which acts in that racked-arc. By turning that winch, the observer in the chair can bring his eye with great delicacy to the eye-piece of the telescope. The winch axis of 78 can be bent down, so as to give facility for entering or leaving the chair.

The motions effected by the three winches 68, 75, and 78, are of great importance for the ease of the person and for the accuracy of observation.

80 and 81, ladder and steps for ascending to the sliding-chair when in its higher positions.

82, a supplementary sliding-chair for observing objects near the zenith. It has no seat, no foot-board, no apparatus for raising it, and none for fixing it (for which, friction is sufficient); the back is supported by a racked-arm, jointed to the back, whose ratchet-teeth lodge on a cross bar.

Figure **46** is the chair-frame and chair intended for observing objects very near to the pole; drawn on the same scale of 1 inch to 5 feet.

83, a frame, which can be passed through the space in which the telescope turns between the two great prismatic frames of the polar-axis, and can be lodged upon the circle 32 in figures **4** and **5**, without resting on any part of the equatoreal-frame. It has a pin at each end, which lodges in one of the holes of the circle 32 in figures **4** and **5.**

84, the sliding-chair; its sliding-frame can be fixed by a simple hook lodging upon pins; and either end of the chair can be raised and supported by a hook lodging on a ratchet.

PLATE VII.

This plate is entirely devoted to the mechanism of the clock-work driven by the pressure of water, for turning the polar-frame of the Equatoreal in the same direction as the apparent diurnal motion of the heavens, and with the same angular speed. Figure **47** is on a scale of $\frac{1}{32}$; figures **48, 48*, 49,** on a scale of $\frac{1}{8}$; all the other figures on a scale of $\frac{1}{16}$. Figures **50** and **52*** are horizontal planes; all the others are vertical.

1 is the south pier, the same as 8 in the figures of Plate I. In figures **47, 51,** and **54,** 1 is the nearly eastern face of the pier; in figures **50, 52, 53,** 1 is the section of the pier.

2, 2, the cast-iron flat fixed to the pier, which carries all the machinery of the clock-movement.

3, the upper bracket of 2, bearing the pendulum-suspension.

4, the lower bracket of 2, bearing the principal moving parts.

5, a bridge carried by 4, which supports the bearing of the great toothed-wheel 31. (Above 5 there is a wooden floor, omitted in these diagrams.)

6, an arch which carries the upper part of the axis of the reaction-machine.

7, an arch which carries above its top the annular cistern 54.

7*, a cross-bar at mid-height of 7. The middle part of 7* is cut out, so that it produces the effect of two cross-bars. The lowest surface carries the upper bearing of the axis of the wheels 31 and 32; the middle vacancy carries the upper and lower bearings of the vertical axis of the rotating or oscillating bar 35 in figure **52*** (which is represented in horizontal plan); and the upper surface carries the lower bearing of 45, which is the spindle of the wheel 44 and of the spade-machinery 46, 47, 50, 51, 52, 53 in figure **49.**

8 is that portion of the water-supply-pipe, led immediately from the main-pipe of the Kent Waterworks, which the water passes before arriving at the self-regulating tap 42; corresponding generally to 13 of Plate I.

8* is that portion of the pipe which the water passes after the tap 42.

9, an air-gauge communicating with 8, for showing the pressure of the water in the supply-pipe. For working the clock properly, a pressure of nearly 60 feet of water is required. The pressure sometimes exceeds 100 feet, but the clock spontaneously adapts itself to this, by the action of the "Siemens' Chronometric Governor," to be described below.

10, 10, 10, air-vessels for experimental purposes, communicating with different parts of the supply-pipe.

11, the master-tap of the supply-pipe 8.

12, the rod leading from the apparatus of figure **51*** (which is the same as 38, 39, 40, in figures **24** and **24***), by which a person in the Upper or Equatoreal Room can open or close the tap 11, and can thus open or close the supply of water in 8. The horizontal section of 12 appears in 25 of Plate I.

12*, a weight on the tap-lever, greater than is required for merely opening the tap. By the action of this weight, the rod 12 is always kept in tension.

13, a quadrant with graduations for the information of the person in the Equatoreal Room who is opening or closing the tap.

14, the winch by which he controls the tap. By the ordinary forward turning he draws 12 upwards and closes the tap; by backward turning he permits the weight 12* to fall and open the tap.

It is to be remarked that the relative positions of figures **51** and **51***, as they would be projected on a horizontal plane, are correctly given in the diagrams; but figure **51** is in the lowest room and figure **51*** in the highest room.

15, another branch of the supply-pipe, connecting portions of the pipe on opposite sides of the tap 11.

16, a tap upon 15, by which a person in the lower room can open or close the supply of water. This tap is convenient for experiments on the clock.

17, the case of the reaction-machine.

18, the rotatory-reaction-machine. The machine represented in the diagram is a small one, once introduced for the purpose of trial. That which is now mounted, and which produces the most equable motion, is so large as to approach nearly to the vertical sides of 17. Its lower pivot is of lignum vitæ, turning in a metallic bearing; the pivot and the bearing are perforated, and the water from 8* rises through the perforation.

18*, the discharge-pipe of the water which has passed through 18. There are in fact two discharge-pipes, and the handle 18** determines the selection of the pipe. 18* corresponds to 14 of Plate I.

19, the spindle rising from the reaction-machine into the upper part of the second room or Chronometer Room. If this spindle and the reaction-machine were unconnected with any controlling machinery, the pressure of the water would cause them to revolve very rapidly, perhaps 10 times or 15 times per second. When the connexion with the controlling mechanism adjusted by the pendulum is properly arranged, 19 revolves exactly 4 times in one second of sidereal time.

20, a bracket attached to the pier 1, in the Chronometer Room, for guiding the rod 19 at one of its points of connexion. It is included in 19 of Plate I.

21, a horizontal disk fixed on 19.

22, a lever loaded with a heavy counterpoise.

23, two anti-friction wheels which it carries (in the diagram, one of these wheels is hidden by the other), pressing 21 upwards, and thus alleviating the pressure at the bottom of 18.

24, a bracket near the ceiling of the Chronometer Room, fixed to the pier 1.

25, a wheel at the top of 19, working in a similar wheel 26 at the bottom of the spindle of the screw 27, which is the same as the screw 26 in figure **27**, Plate IV.

28, the wheel of 480 teeth in which 27 works, the same as 27 of figures **24** and **25**; which carries the great screw, 33 in those figures, that drives the Equatoreal Circle 14, revolving, when all adjustments are correct, in two minutes of sidereal time.

28*, a brush-wheel dipping in oil, for oiling the teeth of 28.

29, the gearing-apparatus for the action of 27 in 28; the same as 28, 29, figure **27**.

30, the pinion on 19, revolving with the reaction-machine, and therefore intended to revolve four times in one sidereal second. It has 55 teeth.

31, a wheel containing 440 teeth, or eight times as many teeth as 30, intended to revolve once in two sidereal seconds.

32, a bevelled-wheel fixed on the same axis as 31.

For the understanding of the next references, it is necessary to remark that figure **52** is in a vertical plane, and **52*** in a horizontal plane.

33 is an arm turning in a horizontal plane round a vertical axis in the middle vacancy of the cross bar 7*.

34, a bevelled-wheel carried by the moveable arm 33. 34 is driven by 32, and drives the bevelled-wheel 44.

35, the connexion of the opposite end of the moveable arm 33 with the middle of the sliding-rod 36, 36.

36, 36, a rod connected with two rectangular levers 37, 37.

38, 38, the rods of two pistons sliding loosely in two water cisterns, to check any rapid motion or any systematic oscillation of the arm 33.

39, a rod (having a screw-adjustment for length) connecting the horizontal movements of 36 with the vertical movements of the lever 40.

41, a lever connected with 40 by a connecting-rod. The places of connexion can be altered, so that the proportion of the angular movements of 40 and 41 can be varied. It will be seen that 41 is the lever which turns the tap 42. (The levers 40 and 41 are here represented, for clearness, as if their lengths were perpendicular to the face of the pier; in fact, they are parallel to the face of the pier.)

42, the self-adjusting tap which regulates the flow of water through the pipe 8* to drive the reaction machine. It is an elliptical disk, turning upon an axis which is a diameter of the disk, and which passes transversely through the center of the pipe; when the plane of the disk is nearly transverse to the pipe, the passage of water is stopped. The descent of 39 closes the tap.

43, an adjustable weight, whose action tends to open the tap 42.

44, a bevelled-wheel, driven by 34. It is fixed upon the axis 45, which carries 46, 47, 50, 51, 52, 53, in figure **49.**

46, an arm, revolving in a horizontal plane, carrying the counterpoise 47, and the spade-apparatus 50 to 53. At the left-hand end of 46 are seen the ends of two pins; the upper pin is the center of motion for the apparatus 50 to 53; the lower pin is only a check to prevent destructive motion of that apparatus in accidental circumstances.

48, the pendulum-cistern carrying 32 lbs. of quicksilver. The motion of the pendulum is conical.

49, a spike projecting from the bottom of the pendulum-cistern. It is embraced by a sliding-collar, connected with 50 by pins, so that the sliding-collar can turn relatively to 50 in the vertical plane.

50, the arm of the spade-apparatus by which the arm 46 acts on the pendulum. In figure **51,** 50 will be seen in a different position. It is to be remarked that 50, 51, 52, 53, are firmly connected.

51, a counterpoise, bearing a graduation for observation of position of the spade-apparatus.

52, a small adjustable weight.

53, the spade, to be dipped in the water 55 of the annular-cistern 54. When the pendulum-rod 67 and the bob 48 are inclined at a certain angle to the vertical, or rotate in a conical surface of a certain angle, the arm 50 is thrown to a distance from the center, and 53 is made to dip in the water 55.

The peculiar and important advantage of thus resisting the circular-motion of the pendulum consists in this: that the resistance is entirely in the direction of a tangent to the circle described by the pendulum, and in no degree in the direction of the radius. All resistances produced by friction give rise to a force in the direction of the radius, and thus modify the time of the pendulum's conical rotation.

54*, an overflow-cistern, to receive water which may be thrown accidentally from 54.

56, 56, 56, small water-pipes for supplying water to 54, and to the cisterns of 38, 38.

57, a sluice for escape of the water 55, if it is too high.

58, in figures **47, 48, 51,** the sliding-plate which carries the pendulum suspension.

59, four screws for adjusting it.

60, 60, in figures **48** and **48***, the pair of springs which support the lower arm 63 of the cross 63, 64, and permit it to oscillate in the direction normal to the paper of figure **48**.

61, 61, screws which support 60, 60.

62, 62, clips which determine the oscillating-point of 60, 60.

63, 64, a cross, which, as viewed from above, presents the appearance of a simple rectangular cross; but, as viewed horizontally in one direction, exhibits the upper part 64 as a semicircle, or rather a bow, with its concavity upwards; and, as viewed horizontally in another direction, exhibits the lower part 63 as a bow, with its concavity downwards. The horns of the upper bow 64 are as nearly as possible at the same elevation as the clips 62, 62.

65, 65, the pair of springs attached to the upper horns of 64, supporting the bow 66, and permitting it to oscillate in the plane parallel to the paper of figure **48**.

67, the pendulum rod, fixed to 66.

It will be seen that, by the flexure of the pair of springs 60 in the direction normal to the paper of figure **48**, and the flexure of the pair of springs 65 parallel to that paper, the pendulum rod 67 is free to vibrate in any direction, and may describe at any point of its length an ellipse, a circle, or any other curve. But the bob 48 does not rotate round the axis of 67.

We may now describe the action of the various forces acting near the lower part of the pendulum and the reaction-machine. The adaptation to these of the mechanism, so as to produce remarkably uniform motion, constitutes the principle of Siemens' Chronometric Governor.

The pendulum 48, supported with the freedom of motion described above, would, in the general mathematical case, rotate in an ellipse, with angular motion necessarily not uniform round its center. But in that case the angular motion of 44 would not be uniform. The tendency of the rapid rotation of 18 and other parts of the machinery is to make the motion of 32 very nearly uniform. These two motions can be reconciled only by an oscillatory movement of the center of the intermediate wheel 34, and a consequent oscillation of the arm 35 round its vertical axis (normal to the paper in figure **52***), and an oscillatory sliding of 36, and an oscillation of the pistons of 38, 38, in the water of their cisterns. The slight resistance of the water tends to restrain forcibly the discordance of movements, and in a very short time the pendulum swings in a circle. This will be assumed in what follows.

In the normal state of motion a power is produced by the reaction-machine 18, revolving in the direction shown by the arrow in figure **50**, which is principally employed in moving the equatoreal, and overcoming frictions of various kinds, leaving a portion to be employed on the clock, driving the wheels 31 and 32.

This power, acting through the wheel 32, turns the wheel 34 by pressing its lower part, in figures **52** and **52***, towards the right, and the upper part of 34 presses the distant part of 44 towards the left, causing 46 and the pendulum to turn in the direction opposite to 31 and 32. The pendulum spade 53, for a reason to be hereafter stated, dips a certain depth in the water (not so deeply as is shown in figure **51**), and thus there is a resistance to the motion of the upper part of 34 towards the left. This requires a pressure from the distant edge of 32, upon the lower part of 34, towards the right. From both these actions the horizontal axis of 34 is pressed to the right, or the junction point 35 is pressed to the left. To meet this pressure, the weight 43 pulls it to the right. Thus it will be seen that the weight 43 determines the horizontal pressure on the horizontal axis of 34, and therefore determines the pressure on 44 which causes 46 and 48 to circulate, and therefore determines (in the normal state) the dip of 53 in the water which will produce the counteracting resistance.

But the position of 43 is determined by another circumstance. It must (in the normal state) open the tap 42 exactly so far as to allow a flow of water sufficient, under the actual water pressure, to move the equatoreal, &c., and to supply the required force on 32.

Thus, in the normal state of motion,—

The weight of 43 determines the dip of 53;

The pressure of the water determines the position of 43.

Now suppose the pressure of water to be increased (or the machinery-friction to be diminished, which produces the same effect), the motion of the distant part of 32 towards the right is immediately accelerated. An additional force is at the same time impressed on the distant part of 44 towards the left, but it will not immediately increase the angular velocity of the pendulum, or the diameter of the circle described by the pendulum. Therefore the intermediate wheel 34 must bodily be moved to the right; 35 and 36 will be carried to the left; 39, 40, and 41, will be dropped; and the tap 42 will be partially closed, thus limiting the supply of water whose pressure has become too great. The angular velocity of the pendulum, meanwhile, has been a little increased, and its circle of motion has become a little larger, and 53 dips a little deeper; the increased resistance on 53 soon reduces the pendulum-circle. In a very short time everything is in a new normal state, differing from the old one only in this respect, that 43 is a little higher than before.

If the power is a little diminished, similar changes in the opposite direction take place. Now, the weight of 43 opens the tap 42. It is necessary therefore that there be a weight 43; and, as this weight determines the resistance of the water 55 to the spade 53, it is necessary that there be a resistance, or that 53 always dip in the water. It is necessary also for another reason. We have remarked, in the case of increased power, that 53 dips a little deeper, and that this deepening soon reduces the pendulum-circle. Here, on the other hand, 53 will be a little withdrawn, and, if it be not in the water, there will be no diminution of resistance, and no tendency to restore the pendulum-circle.

In practice, a slight quivering is seen from time to time in the position of 35, but nothing that can be visible as affecting the view of an object in the telescope. It is found best to open the tap 8 not much wider than is quite necessary. A small apparatus (omitted in the drawings) is attached to the wheel 28, by which at pleasure a bell is struck at a certain position of the wheel, and by which therefore the rate of the clock is ascertained. From hour to hour the rate is sensibly the same, to a small fraction of a second of time. I believe the motion to be the most uniform which exists.

PLATE VIII.

This plate gives a general view of the interior of the dome and the instrument; but, after the great detail of explanation of parts, it does not appear necessary to give any further description of the whole as seen in this view.

The primary plans of the building and instrument were, in nearly every point, arranged by me.

The builders' work and carpenters' work were executed by tradesmen resident in the neighbourhood, usually employed at the Royal Observatory.

The whole of the iron-work and portions of the brass-work, including the water-clock, the supports of the equatoreal, the polar-frame, the endless-screws and the equatoreal-circle, the declination-axis and circles, the rings and springs for galvanic communication, the machinery of the chair, and the machinery of the dome, were made by Messrs. Ransomes & Sims (formerly Ransomes & May).

The mounting of the object-glass, the eye-piece, and all work attached to it, the graduation of the circles, the bridle-rods and their graduation, and other instrument-makers' work, were done by Mr. Simms (Troughton and Simms).

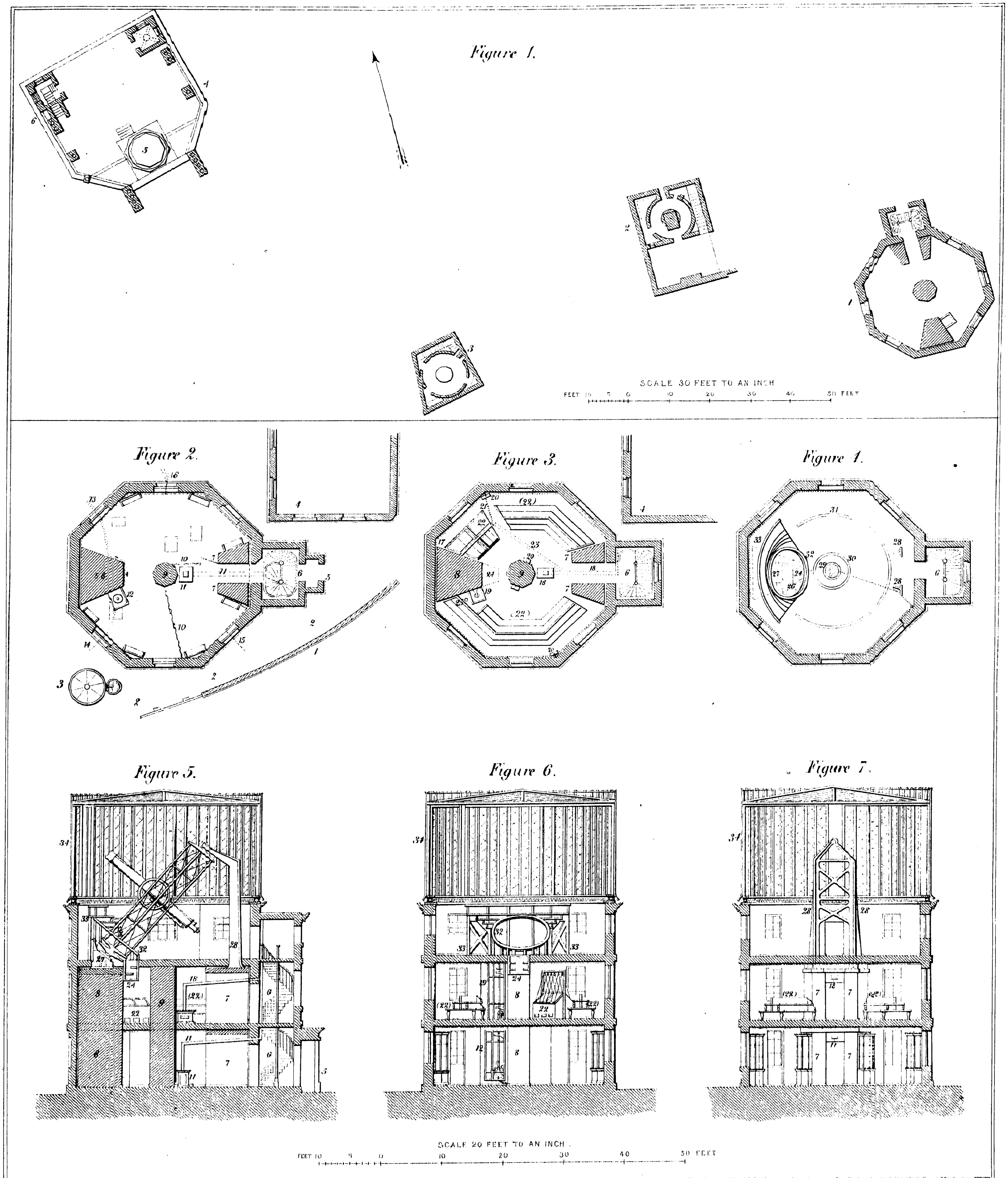
The object-glass was furnished by Messrs. Merz and Son.

G. B. AIRY.

1869, *December* 23.

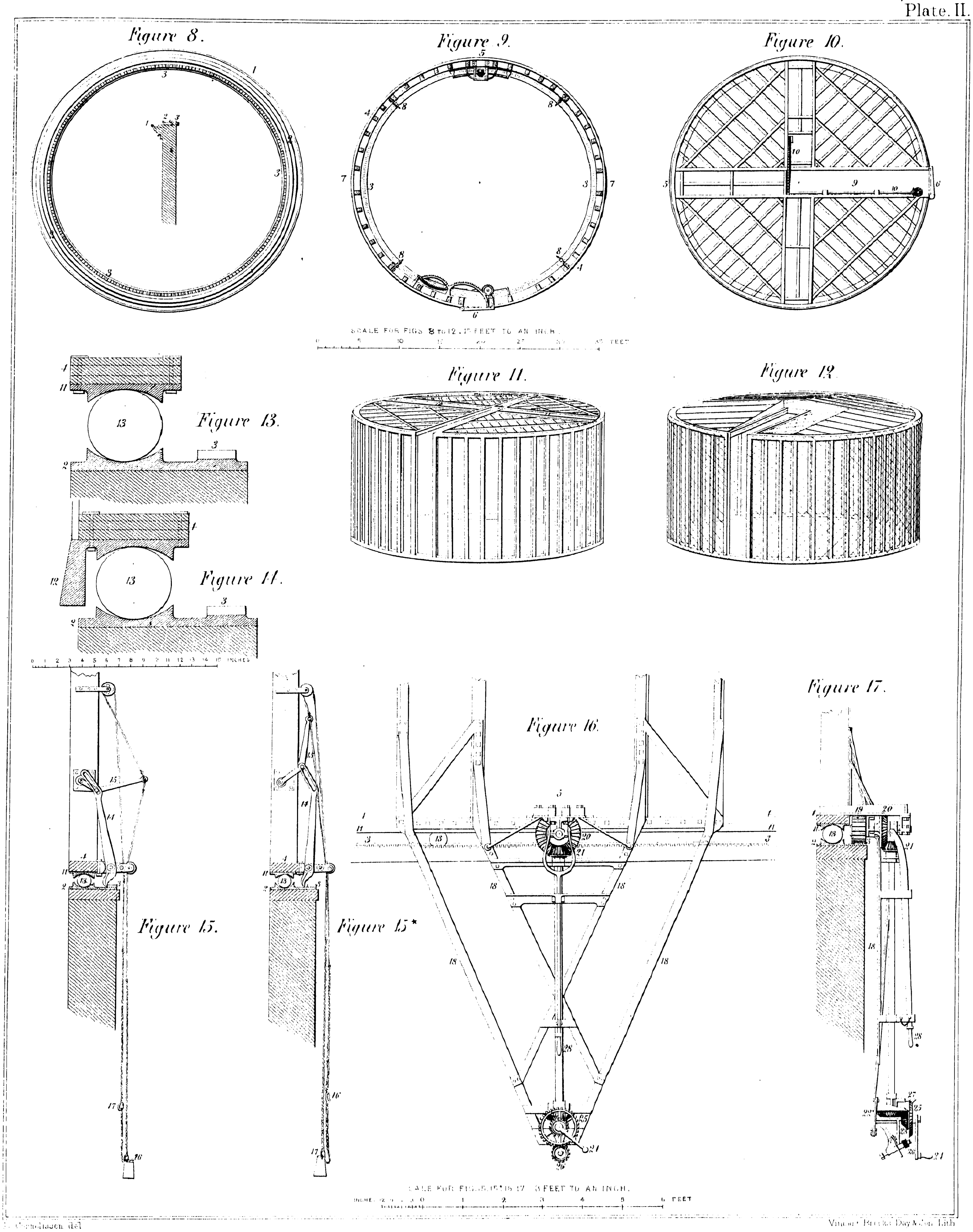
ROYAL OBSERVATORY, GREENWICH. GREAT EQUATOREAL.

Plate I.



ROYAL OBSERVATORY, GREENWICH. GREAT EQUATOREAL.

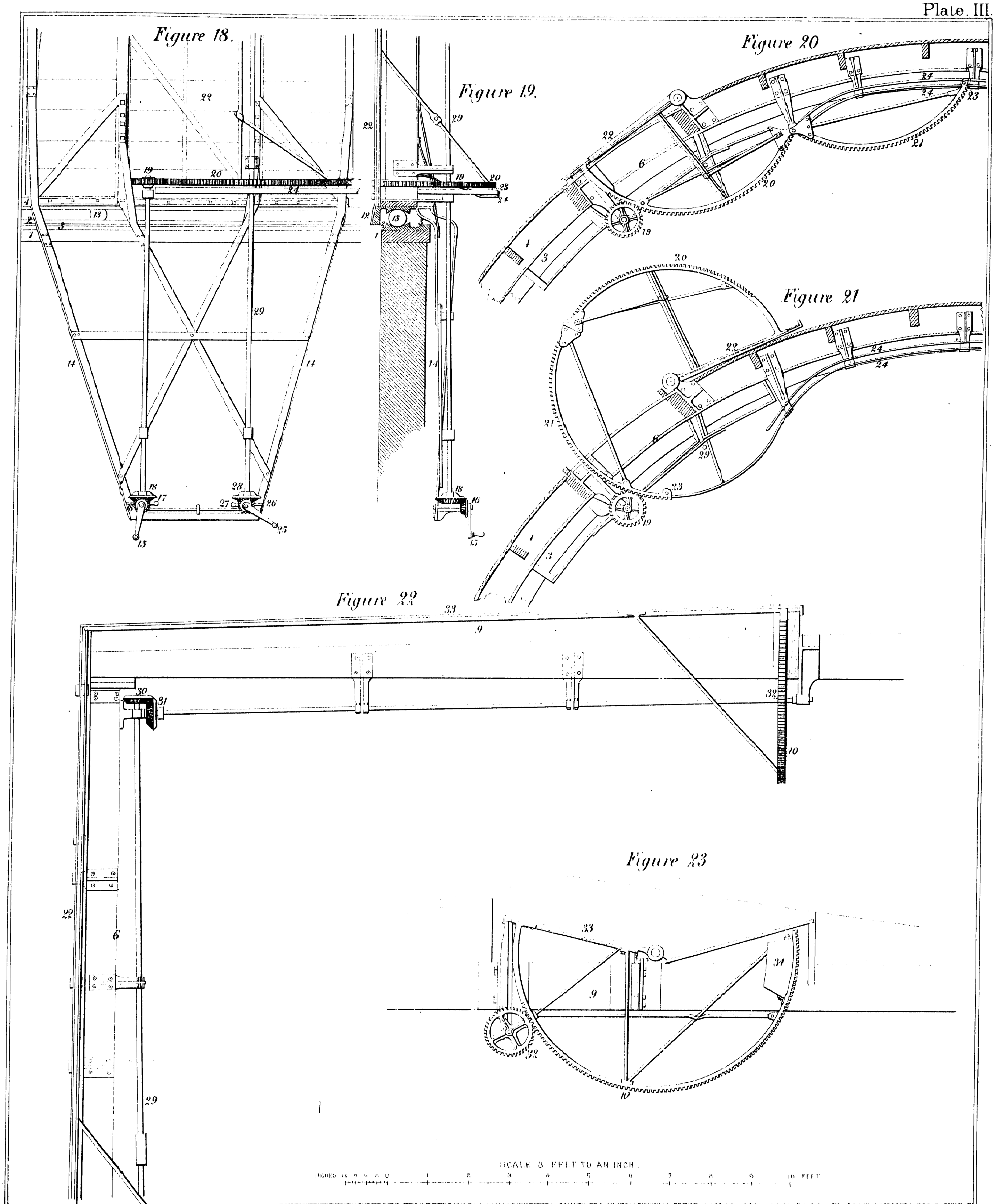
Plate. II.



Vincent Brooks Day & Son, Lith

ROYAL OBSERVATORY, GREENWICH. GREAT EQUATOREAL.

Plate. III.



L. Cornelissen del.

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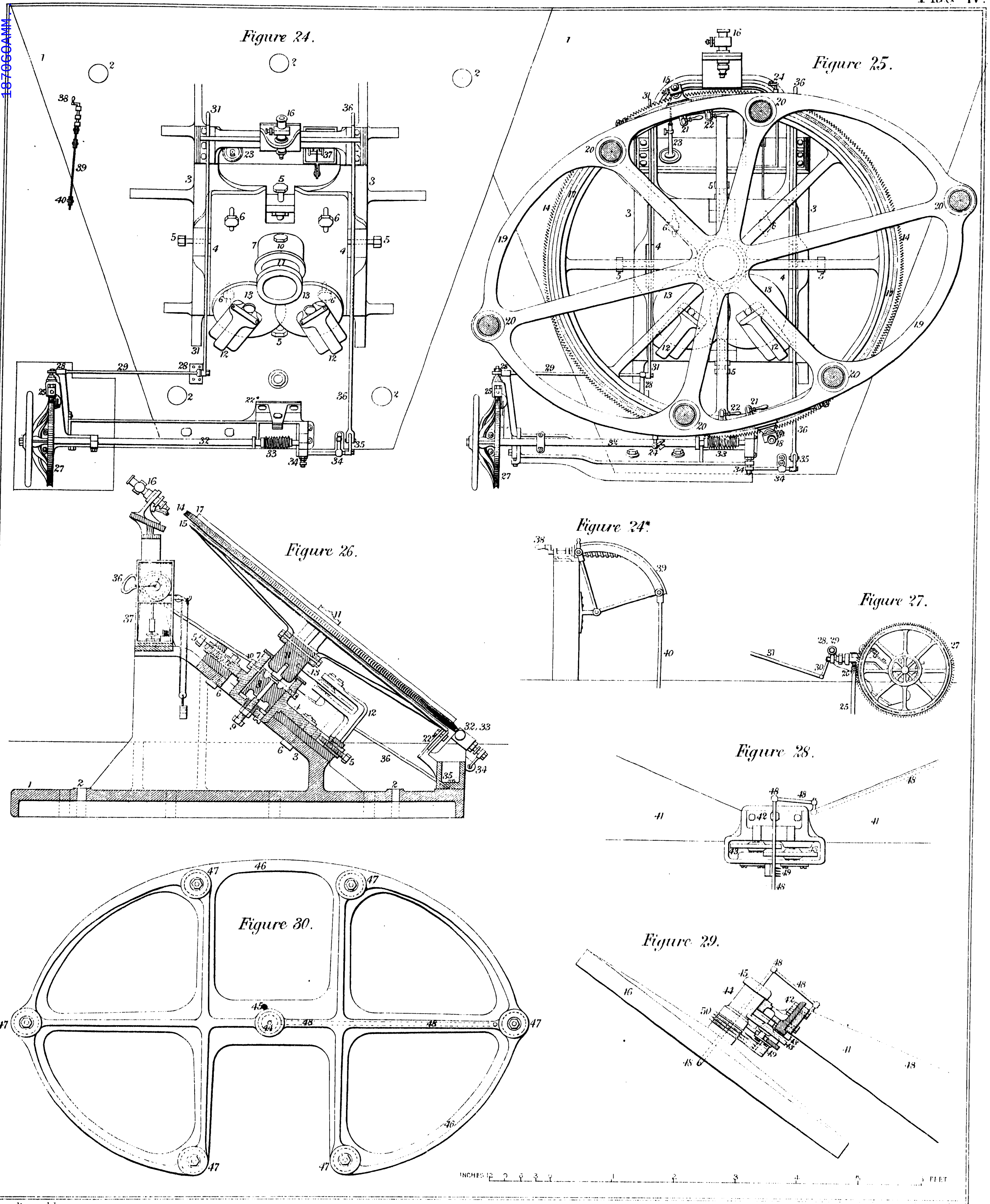
ROYAL OBSERVATORY, GREENWICH. GREAT EQUATOREAL.

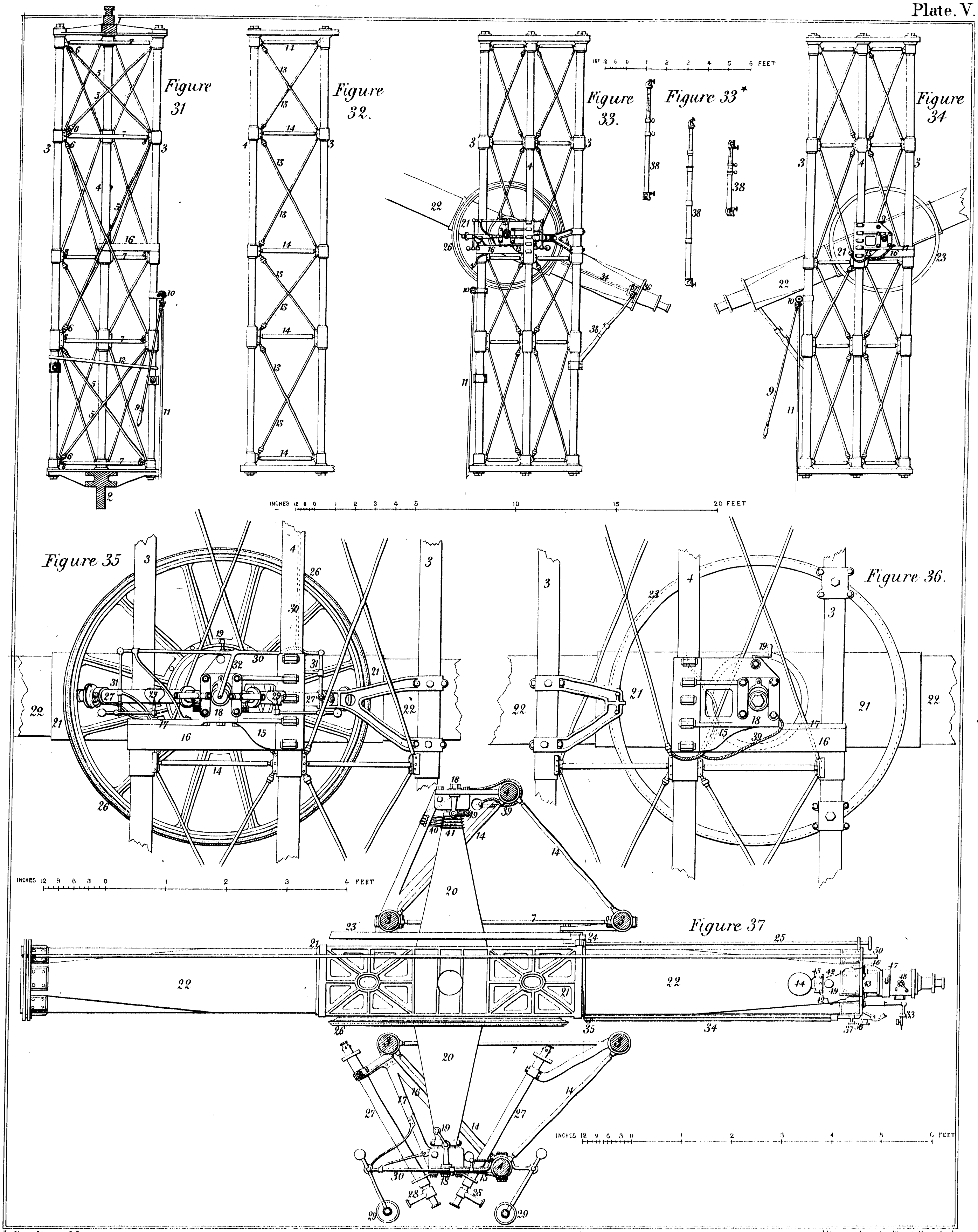
Plate IV.



L. Cornelissen, del.

ROYAL OBSERVATORY, GREENWICH. GREAT EQUATOREAL.

Plate. V.



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ROYAL OBSERVATORY, GREENWICH. GREAT EQUATOREAL.

Plate VI.

Figure 38.

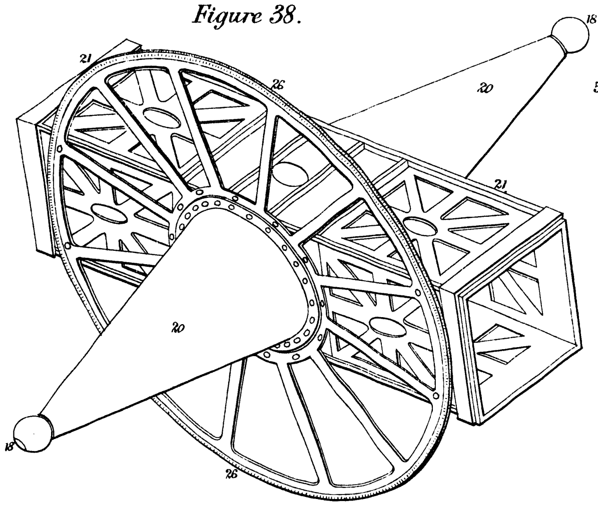


Figure 39.

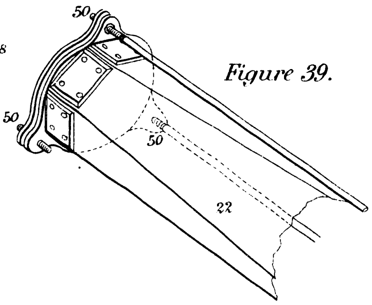
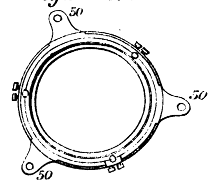
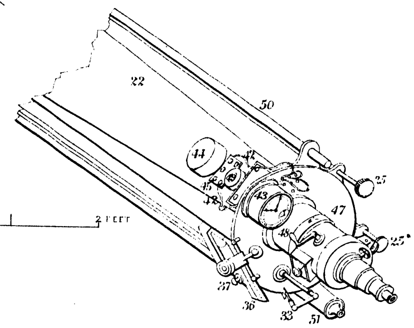


*Figure 39.**





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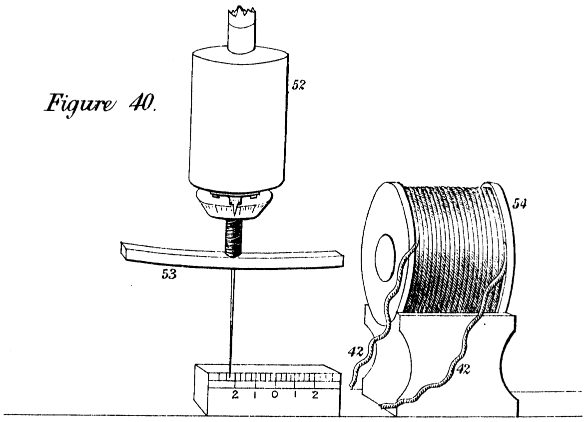

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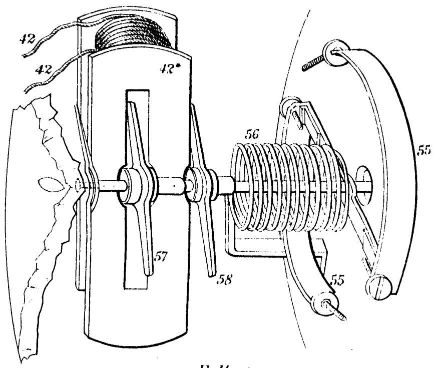


Full size.

Figure 42.

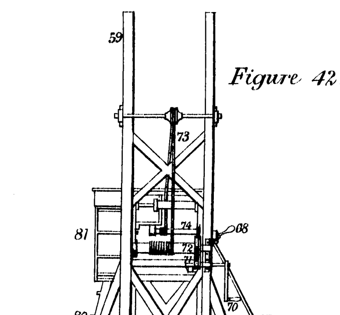


Figure 43.

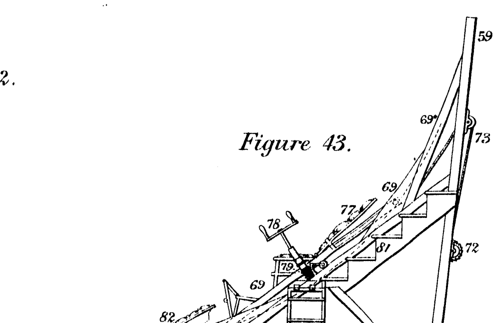
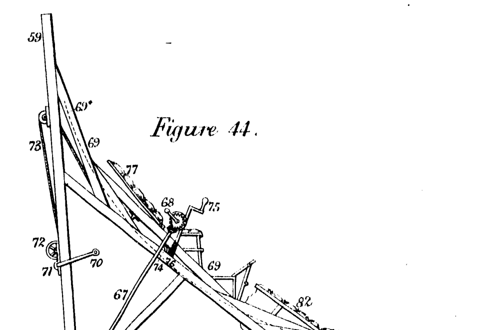


Figure 44.



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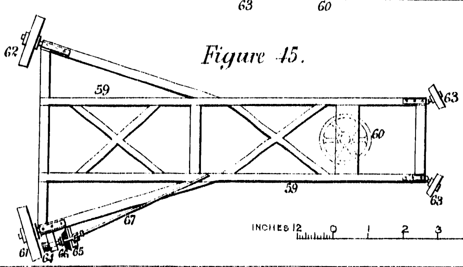
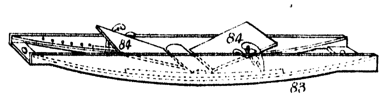


Figure 46.



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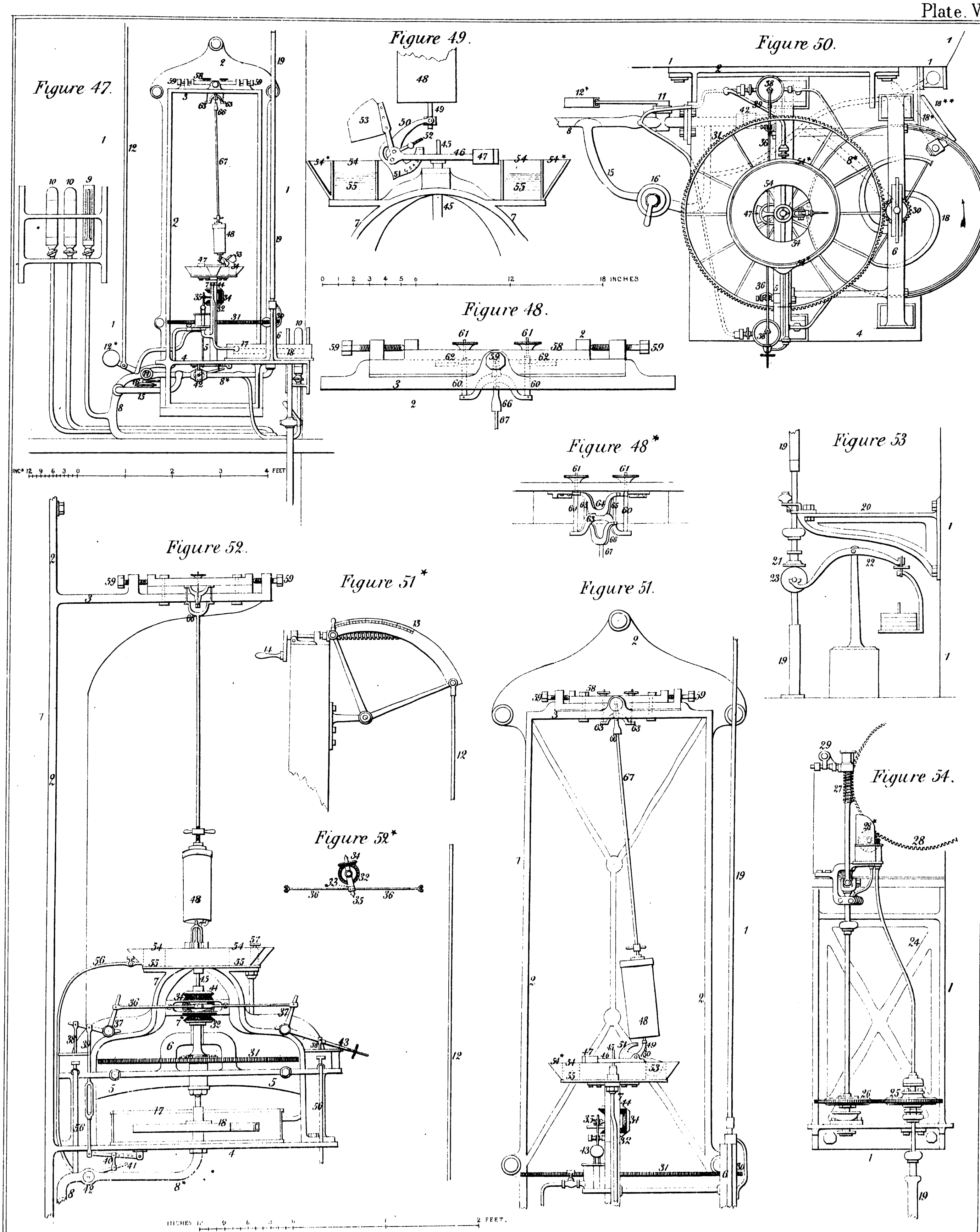
ROYAL OBSERVATORY, GREENWICH. GREAT EQUATOREAL.

Plate. VII.



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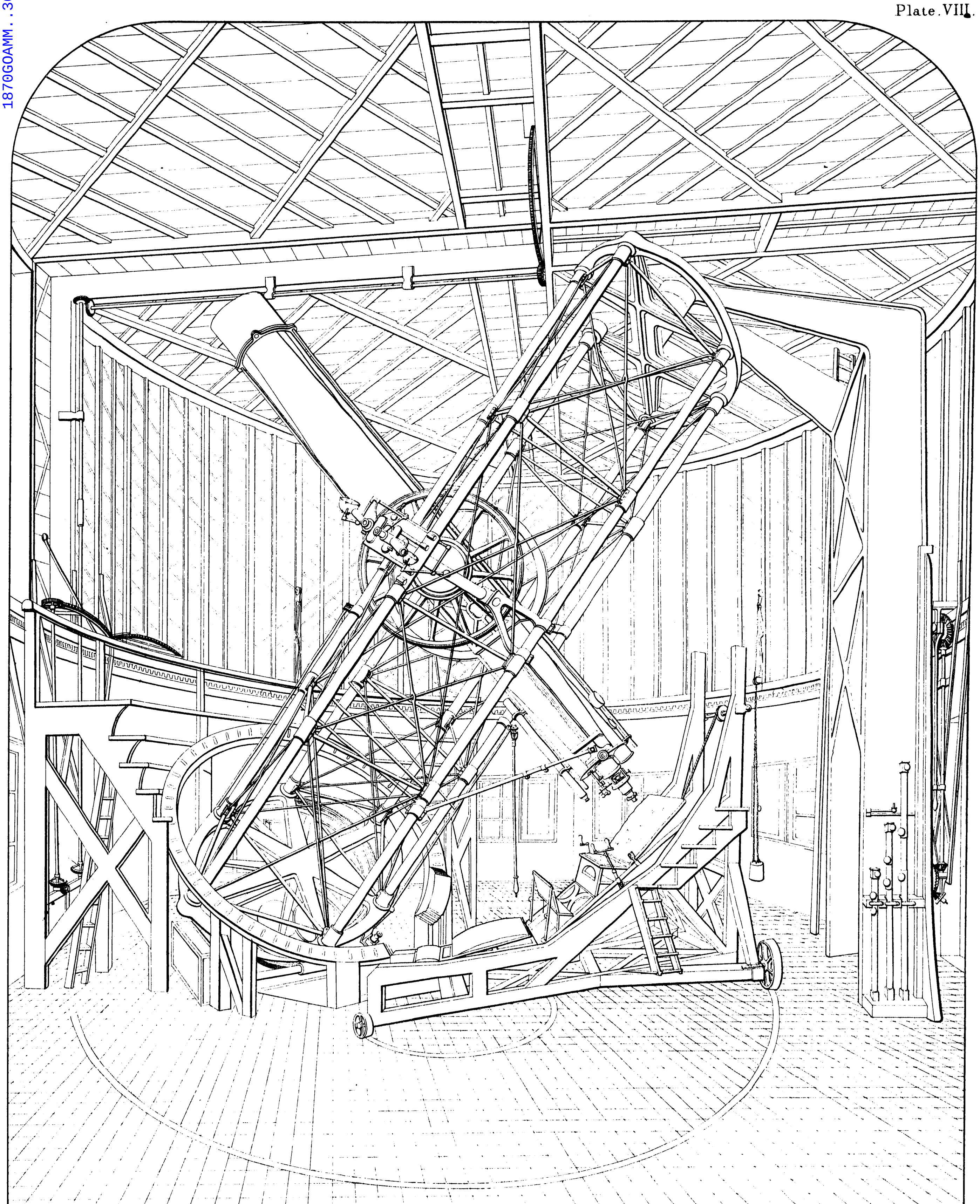
ROYAL OBSERVATORY, GREENWICH. GREAT EQUATOREAL.

Plate. VIII.



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