James Bradley's New Observatory and Instruments

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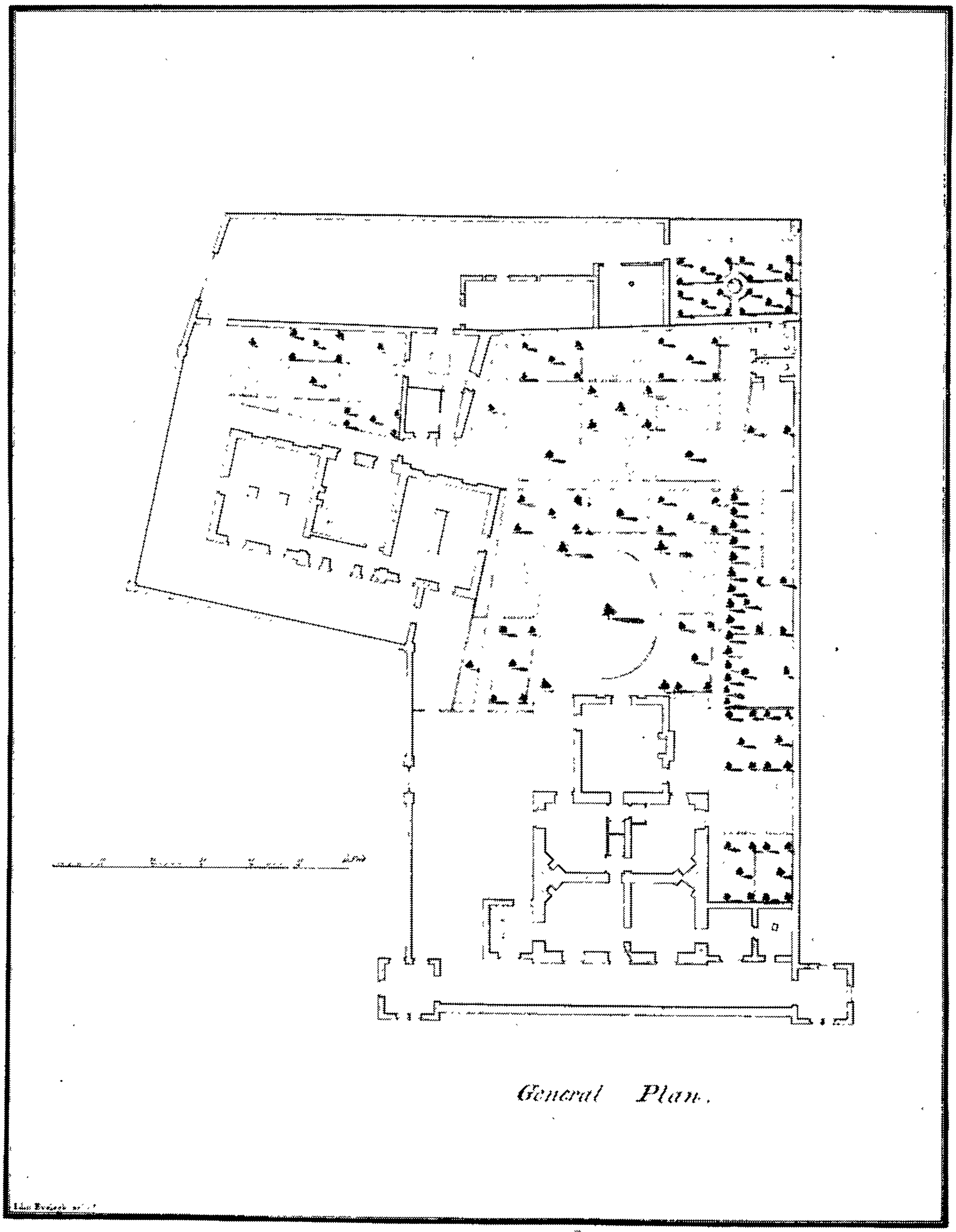
THE ROYAL OBSERVATORY BUILDINGS IN BRADLEY'S TIME

The Royal Observatory, Greenwich, was established by Royal Warrant in 1675 "in order to the finding out of the longitude of places for perfecting navigation and astronomy". The Astronomer Royal's residence and observatory were combined in a small building designed by Sir Christopher Wren and erected on the site of the stronghold in the Royal Park at Greenwich which formerly commanded the south-eastern road and river approaches to the capital. John Flamsteed, the first Astronomer Royal, was succeeded, on his death, by Edmund Halley; James Bradley was his successor and thus the third Astronomer Royal.

Flamsteed's house had consisted of the living rooms, with the domestic offices below, and, above, the Great Room or Octagon Room. This had served as an observing room and office; in the south-east corner of the garden he had had a Sextant House and Mural Arc Room, and, beyond, a 90-foot well zenith telescope for observing   Draconis.

When Halley had succeeded Flamsteed in 1720 he had built a wooden transit shed in the north-west face of the observatory and, in 1721, had installed a transit telescope—of 5-foot focal length—one of the earliest in the country. Four years later he had constructed, to the north of Flamsteed's Sextant House, a Quadrant House, containing a remarkable meridian wall on which he had mounted an 8-foot iron quadrant made by Jonathan Sisson (1690?–1760?) under George Graham's (1673–1753) supervision; but by the time Bradley became Astronomer Royal in 1742 this had become jammed against the roof, Flamsteed's Sextant House was a pigeon loft, and his well telescope was filled in, having failed at an early date.

Bradley soon set about enlarging and improving the Royal Observatory. In 1749 he obtained a grant of £1 000 from George II with which to build a "New Observatory" and acquire new instruments. His new building consisted of four rooms, built on an East-West line (see Plate 4). The western—Quadrant—room incorporated Halley's Quadrant House



A plan of the Royal Observatory, Greenwich, c.1765. On this plate North is towards the bottom. At the North end of the grounds is Flamsteed's house: the shape of the Octagon Room does not show on this ground plan. Bradley's "New Observatory" is above and to the left on the plan: the E–W and N–S lines are exactly indicated by the run of the two piers in the East (Transit) Room and the Meridian Wall in the West (Quadrant) Room.

By Courtesy of the Astronomer Royal

and meridian wall. The central room was the principal office and had above it a room for the Astronomer Royal's assistant. The eastern room housed a new transit instrument which was made for Bradley by John Bird (1709–1776) and installed in 1750. This Transit Room matched the Quadrant Room so that the building was symmetrical. Flamsteed House was restored and opened as part of the National Maritime Museum in 1960, the reconstruction of Flamsteed's Sextant and Quadrant House is planned, and the restoration of Bradley's "New Observatory" is to be undertaken by the Ministry of Public Building and Works before long.

BRADLEY'S ASTRONOMICAL INSTRUMENTS

The National Maritime Museum is fortunate in having inherited from the former Royal Observatory (though not in working order) a quadrant by Abraham Sharp (1651–1742) who made instruments for Flamsteed; Halley's 5-foot transit and level and 8-foot iron quadrant; and no less than five of Bradley's instruments—his $12\frac{1}{2}$-foot Zenith Sector, his 8-foot Brass Quadrant, his Equatorial Sector and $8\frac{1}{2}$-foot Transit and level. These have been or are being restored in the Museum workshops for exhibition.

BRADLEY'S $12\frac{1}{2}$-FOOT ZENITH SECTOR

Made in 1727 by George Graham, this famous instrument was first erected at Wansted inside the house of Bradley's aunt, widow of the astronomer James Pound (1669–1724). With it Bradley discovered the aberration of light (published 1729) and the nutation of the Earth's axis (published 1748)

In 1749 Bradley, being allowed £45 for the instrument out of his £1 000 grant, removed it to the Royal Observatory where it was hung by the instrument maker Hearn. Two suspensions were put up in the Quadrant Room, one facing East and the other West, and another in the Transit Room. The object was to observe absolute zenith distances for correcting the collimation of the quadrants.

The tube of the telescope, which constitutes the radius, is 12 feet 6·6 inches long and constructed of riveted iron plates, tinned over. The whole was originally suspended at the top of two horizontal cylinders, placed directly opposite each other on contrary sides of the object glass, which was of 12-feet 6·8-inch focus and 2·85-inch aperture. The $12\frac{1}{2}°$ arc was originally made of brass and fixed to the tube exactly against the cross-wires ($\frac{1}{440}$ inch thick or 3·11 seconds of arc) in the common focus of the object glass and eyepiece, the focus of which was 2·2 inches, giving a power of about 68. The arc was divided to 5 minutes of arc.

Parallel to this arc and at the same height, but behind the telescope and in the plane of the meridian, was the micrometer screw and backlash cord. One revolution of the micrometer screw amounted to 0·0246 inch and it was calculated that with the 2·2-inch eyepiece, the eye could detect anything greater than half a second of arc.

Originally there was a notch in the centre of the instrument into which the plumb-line fitted (the wire was $\frac{1}{100}$ inch thick and could support a weight of 18 oz). The tinned tube and brass hoops at the end weighed 8 lb 15 oz, and the rest of the apparatus fixed to the tube amounted to an additional 6 lb 4 oz. The sector was hung with great care and it was estimated that it could be rectified to a quarter of a second of arc.

Nevil Maskelyne (1732–1811), Astronomer Royal 1765–1811, had the suspension altered, presumably to that from which the instrument now hangs, and in 1777 replaced the brass arc with one of iron with gold studs let in at the divisions. In 1785 he replaced this with the present gold-studded steel arc (see Plate 5(*a*)). In 1789 he added a concave mirror for illumination and, in 1801, fitted an achromatic object glass.

Bradley's Zenith Sector remained in the Quadrant Room until 1837 when it was taken down on August 4 and shipped to the Cape of Good Hope to assist in the survey of the colony which was then in progress. It was returned to Greenwich in about 1851 when it ceased to be used. It is now exhibited in the Octagon Room of the Old Royal Observatory.

BRADLEY'S 8-FOOT BRASS QUADRANT

Made by John Bird for £300, it was paid for out of the 1749 grant. The design was similar to that of Halley's Iron Quadrant. This had been installed facing South on the east face of Halley's Meridian Wall. Bradley's Brass Quadrant (Plate 5(*b*)), delivered on 1750 February 16, was therefore fixed on the West face of the quadrant wall incorporated in the "New Observatory". It remained there from 1750 August 10 to 1753 July 31, when the positions of the two quadrants were reversed. Both quadrants are now being restored and will be rehung, when the restoration of Bradley's New Observatory is completed, on the quadrant wall—Bradley's on the East face facing South, Halley's on the West face facing North.

Like Halley's 8-foot quadrant the rim of Bradley's was divided into 90° on the inner edge and 96 equal parts on the outer (for ease of dividing). The length of the telescope, like that of Halley's Iron Quadrant, was 8 feet 8 inches, the working aperture was 1·32 inches (although the outside diameter of the O.G. was 2·27 inches) and the focus of the eyepiece 2·13 inches; the power was 45 and the field 44 minutes of arc.

In about 1742 Bradley had fitted to Halley's Iron Quadrant his device for illuminating the field by light reflected down the tube, and in 1745 he had had a micrometer showing seconds made and fitted by Sisson. These features were incorporated in the design of the Brass Quadrant. The first major alteration was not made until 1772 July when an achromatic object glass was put in by Peter Dollond (1730–1820). This had an aperture of 2·31 and a focal length of 97 inches. At the same time a single movable eyepiece of 1·57 inches focal length was fitted, increasing the power to 62. In 1777 an improved system of illumination was introduced. Three years later Maskelyne recommended that "small openings be made in the tubes of the Telescopes of the Mural Quadrants near the object glass to admit the free circulation of air through the tubes and thereby render the calculation of the refraction of the heavenly bodies relative to the temperature of the air in the middle of the tube, shewn by the thermometer placed there, more certain". At the same time "16 red and 16 green silk tassells [were] to be annexed to the silk lines to draw and shut the shutters".

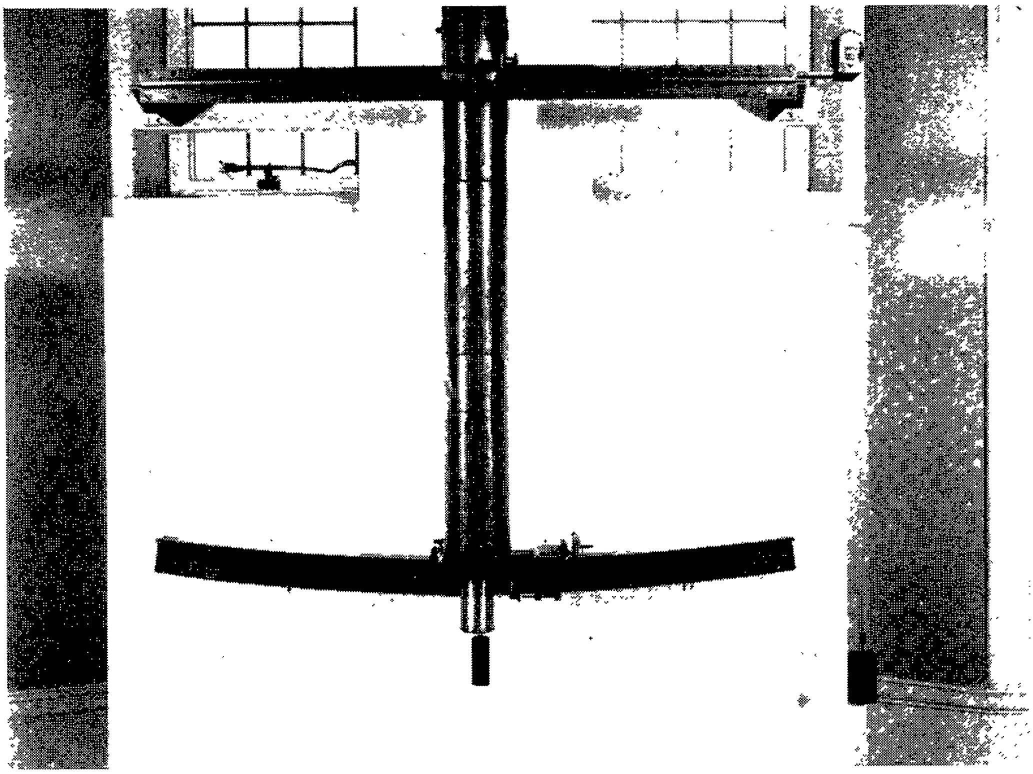
Reading glasses for the verniers and revolution-counters were added in 1787, while in 1789 Aubert's apparatus (for taking the weight off the telescope bearing) was also adopted. In 1790 specula were added to reflect light from the zenith to illuminate the plumb line by which the instrument was set; the verniers were also improved.

In 1792 Maskelyne fitted an eyepiece of longer focus for the use of his assistant, Benedict Chapman, who was nearer sighted than himself, and in 1801 August new micrometers were fitted by Huggins.

The two quadrants were used side by side until the introduction of the revolutionary Mural Circle in 1812, when the maximum error of the Brass Quadrant at a zenith distance of 85° was as much as 8 to 10 seconds of arc. A few declination observations were made in 1824, but this marked the end of the use of the quadrants in the Royal Observatory.

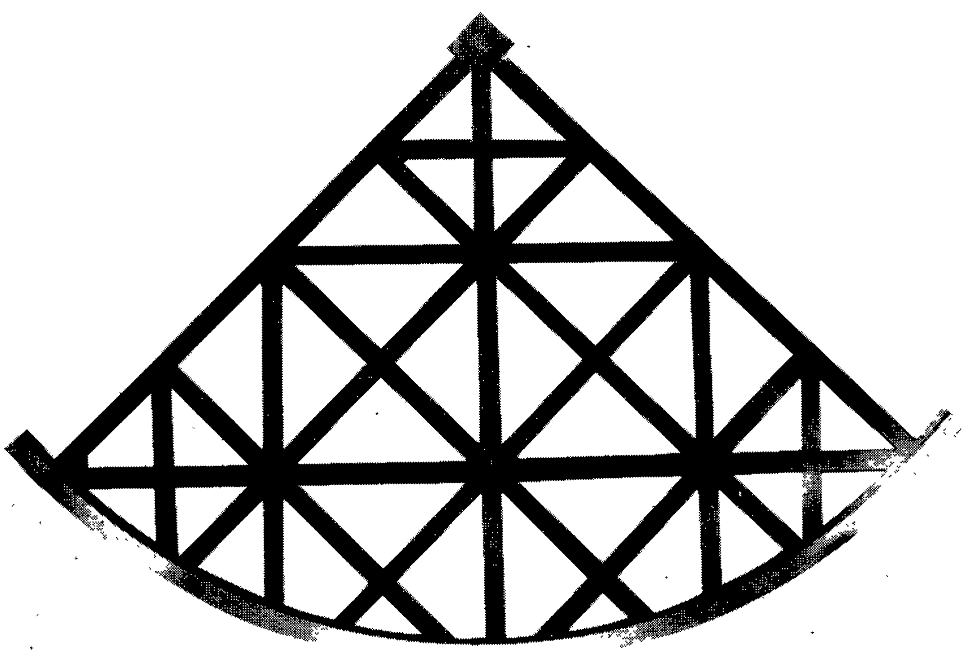
BRADLEY'S TRANSIT INSTRUMENTS AND LEVELS

When James Bradley became Astronomer Royal on Halley's death in 1742, he had Halley's transit altered and balanced by the instrument-maker Sisson at a cost of £19 8s 0d. This 5-foot telescope, mounted off-centre on a lattice axial frame, was mounted in brass notches let into separate stone pillars erected in the hut which Halley had built between the dwellinghouse and the North West summerhouse. Two more vertical wires 15 minutes of arc away from the existing central one were also added, although, strangely enough, Bradley did not often employ all three when making transit observations.



(*a*). Present state of the lower part of Bradley's 12½-foot Zenith Sector, originally made by George Graham in 1727.

By Courtesy of the Trustees of the National Maritime Museum



(*b*). Bradley's 8-foot-radius Brass Mural Quadrant of 1750, made by John Bird.

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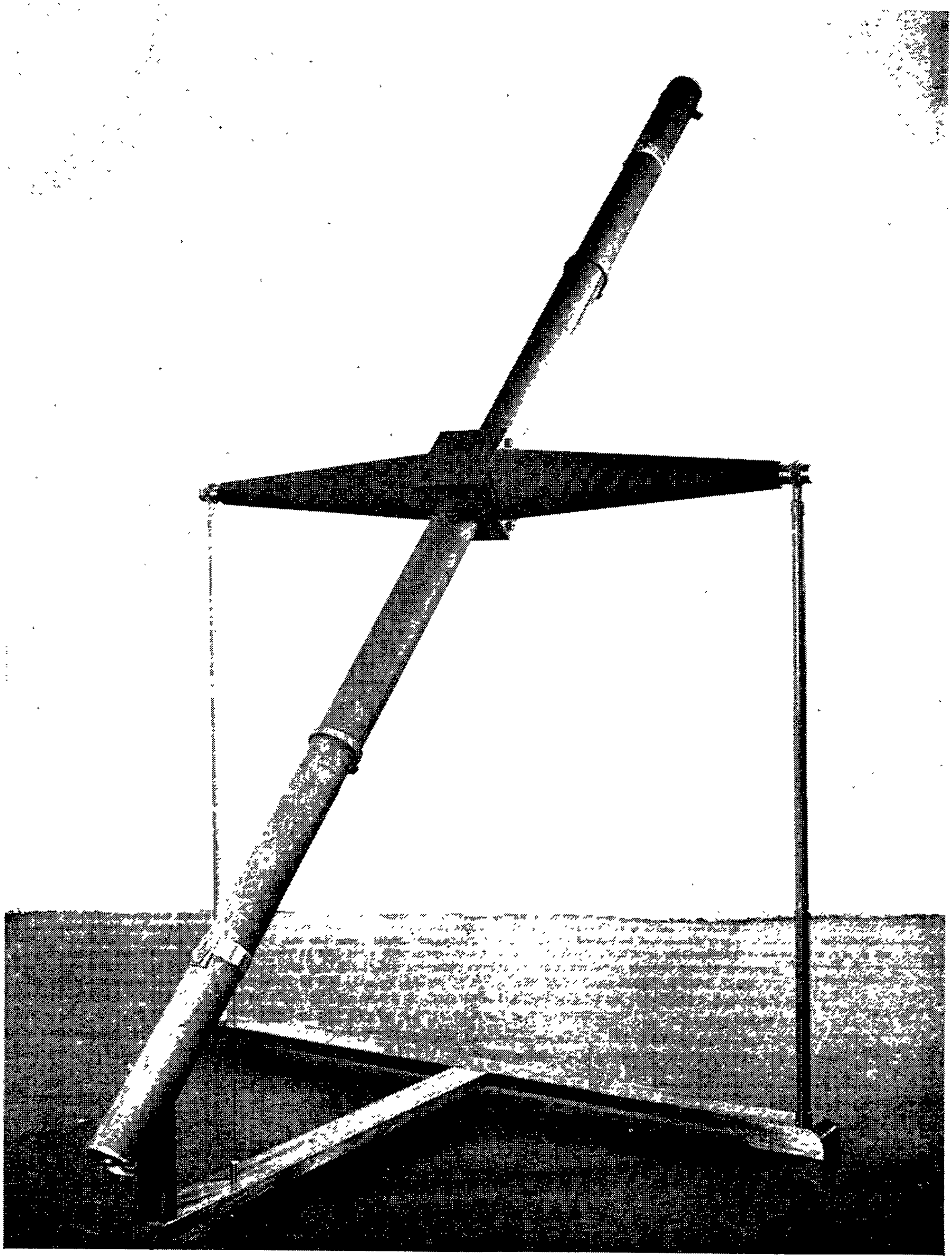

Bradley's Transit of 1750, made by John Bird. The tube is 8 ft 6 in long, and the 4-ft axis is here supported on a temporary display stand.

By Courtesy of the Trustees of the National Maritime Museum

In early 1742 July Bradley had several trees in the Park lopped as they had been allowed to interfere with the observation of the meridian marks, and on 1742 July 25, the first observations were made with the altered instrument, although a regular programme was not begun until 1743 January 1. Bradley also added an illuminating apparatus of his own design, at first a box fixed near the object glass and later by means of an adjustable detached arm. An arc for adjustments and a level were made by John Bird in 1744 and 1747 at a cost of £8 13s 0d and £1 11s 6d respectively. A micrometer was added in 1745 and the instrument further improved in small details by Bird in 1748 for £5 15s 6d.

The last recorded observation was made on 1750 August 31, the object being Capella. The transit remained *in situ* until 1774. It and its level are now exhibited in the Old Royal Observatory.

Bradley superseded Halley's Transit and level with new ones bought out of the grant of 1749. He installed the transit on stone piers erected in the Transit Room of his "New Observatory". Constructed by John Bird at a cost of £73 13s 6d, the transit had an overall length of 8 feet 6 inches and a 4-foot axis. The focal length of the common object glass was 8 feet and there was a single fixed eyepiece of power 50 (Plate 6).

The maximum working aperture was 1·6 inch, the outside diameter of the object glass being only 2·20 inches. The instrument was supported on the stone piers on steel Y's, and a lever being placed on each pier and applied to the end of the axis, counterpoises were moved to reduce the weight until all that rested on the Y's was about 3 lb.

The illumination was by Bradley's own method, i.e., a 45° pasteboard reflector with an elliptical hole at the object-glass end, a lamp below supplying the light to be directed down the tube. The amount of illumination was controlled by a shutter in the lamp box, operated by a cord running to the eye end.

The transit was first used on 1750 September 2, and reversed in 1751 August. In 1752 a new system of eyepieces was introduced to improve the clarity of the field by using two plano-convex lenses in the eye system, with the wires between. The first observations obtained with this were in 1753 January.

On 1753 September 17 the axis was reversed with respect to the tube, but restored to its original position on 1759 November 16, when further new eyepieces were added.

The five wires were unequally spaced, the interval between the outer two on either side of the meridian being double that of the inner. With the original eyepiece, the time taken for an equatorial star to move between the inner wires was 20 seconds. On the introduction of the new system in 1753 the interval became 38 seconds, but was again reduced, this time to 35 seconds, when the third system of eyepieces was brought into use in 1759. All these eyepieces were fixed.

Bradley usually observed on the meridional wire only, and at first recorded his times to the nearest second, except for the Moon and planets. On the introduction of the compound eyepiece he recorded to the nearest $\frac{1}{4}$ second and later still introduced a system of signs to indicate to the nearest $\frac{1}{8}$ second.

In the next sixty years, as observing technique improved and faults were detected, improvements were made to the lenses, housing and mounting of the transit. By 1767, for example, when Nevil Maskelyne was Astronomer Royal, a new system of elliptical illuminators in the axis had superseded the object-glass method of field illumination and five years later Peter Dollond, the instrument-maker, fitted an achromatic object glass; a new level was made for the Transit and purchased in 1774. The Trigonometrical Survey carried out by General Roy used the Royal Observatory as one of its principal stations and in 1787 a theodolite was erected on the roof of Flamsteed House; a scaffold over Bradley's Transit Room enabled the meridian to be linked with the triangulation.

The last observation with Bradley's transit was made on 1816 July 5, when the instrument was dismounted and replaced on the next day by the new transit constructed by Troughton. Both instruments are now exhibited in the Old Royal Observatory, and all three transits will be placed in South Block—Bradley's "New Observatory"—when it is restored.

EQUATORIAL SECTOR BY GRAHAM

Constructed by George Graham for Bradley in 1750, it too was paid for out of the 1749 grant. It was the first instrument of its kind. The telescope, of 30 inches focal length, was fixed to a polar axis and capable of being moved into any meridian. Intended for measuring the distance of comets from fixed stars, the arc along which the tube could be moved was only 6 degrees in length; divisions were cut every 15 minutes and a vernier enabled readings to be taken to 1 minute.

The sector was kept in the Great Room and used there as required, without alteration, until Nevil Maskelyne recommended some improvements on 1770 July 12, at the annual Visitation. However, nothing was done to it and, after the construction of two equatorial sectors and their mounting in the North-East and North-West Terrace domes (in or before 1775), it fell into disuse. The sector arm survives and is to be restored and exhibited in the Great Room where it once was used.

RESTORATION OF BRADLEY'S "NEW OBSERVATORY"

Plans for the restoration of Bradley's observatory and the display of his instruments are being prepared by the Ministry of Public Building and Works in consultation with the National Maritime Museum. The proposals are that Halley's 8-foot Iron and Bradley's 8-foot Brass Quadrants (of 1724 and 1750 respectively) shall go back to their final positions on Halley's Quadrant Wall; that in glazed archways between the lower rooms of Bradley's "New Observatory" shall be mounted, from West to East, Halley's transit of 1721 and Bradley's transit of 1750; and that the transit made for Pond by Troughton shall be mounted, as it was originally in 1816, on the pier used by Bradley for his transit. Troughton's instrument can be shown unglazed as it is still in a sturdy condition. The next room to the East will continue to contain Airy's transit of 1851 and, on the north-east wall (probably) will be mounted the Mural circle made for Maskelyne but finished in 1812 after his death, the most revolutionary instrument after Bradley's transit. In this way it is hoped to display to their best advantage and to preserve for posterity these remarkable instruments of former times. Several will be displayed in their actual working positions within the buildings originally constructed to house them, a feature which makes the National Maritime Museum unique amongst museums in the Western hemisphere and, because it still defines the world's Prime Meridian, in the world.

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