Quality Control in the Making of Scientific Instruments:

Kew Observatory and the Verification of Meteorological, Magnetic and Other Instruments, 1851-1899

D.J. Bryden

Introduction

A Royal Society Committee reported in 1777 that London made thermometers differed by up to 3.25 degrees Fahrenheit at the upper fixed point.[1] Thermometry calibration problems were many and various but the solutions of savants had little impact on trade practice. Change required users to demand comparable instruments. In meteorology it was well into the nineteenth century before the need for accurate and comparable instruments became a matter of concern. In 1832, J.D. Forbes, Professor of Natural Philosophy at Edinburgh, referred to meteorology as 'an infant science', and criticized available instruments - 'for the most part treated like toys, and much time and labour have been lost in making and recording observations utterly useless for any scientific purpose'.[2] In Britain, independent routine verification of meteorological and magnetic equipment was undertaken from the early 1850s as one of the activities at Kew Observatory under the British Association for the Advancement of Science. After 1871 such work continued at Kew, now operated by the Royal Society. The Observatory became part of the National Physical Laboratory, on its establishment in 1900. This paper provides an overview of meteorological, magnetic instrument verification at Kew in the last half of the nineteenth century.

Kew Observatory

Kew Observatory was built for George III for Transit of Venus observations in 1769. It housed the King's scientific instruments, tools, and natural history collections, together with the lecturing equipment of his salaried observer.[3] Succeeding monarchs had little interest in science. By Victoria's reign the observatory was run down, unused, and a drain on government resources. The contents were dispersed, the bulk of the useful astronomical instruments going to Armagh Observatory and the rest of the instruments to King's College London. The government, in response to interests expressed by the Royal Society, offered Kew to them. The Physical Committee of the Royal Society was enthusiastic. Their subcommittee cited various roles for Kew Observatory:

> for occasional observation and comparison of pendulums, either returned from abroad, or about to proceed on voyages, as also affording foreigners wishing to compare pendulums an opportunity of so doing. ... for trial and comparison of magnetical apparatus, and affording to observers desirous of acquiring a knowledge of the nature and use of such apparatus, an opportunity for conveniently doing so, and of obtaining a practical knowledge of the system of magnetic observation recommended by the Society. ... for the trial of physical apparatus and occasional physical experiments ... for the comparison of standards of every description 4

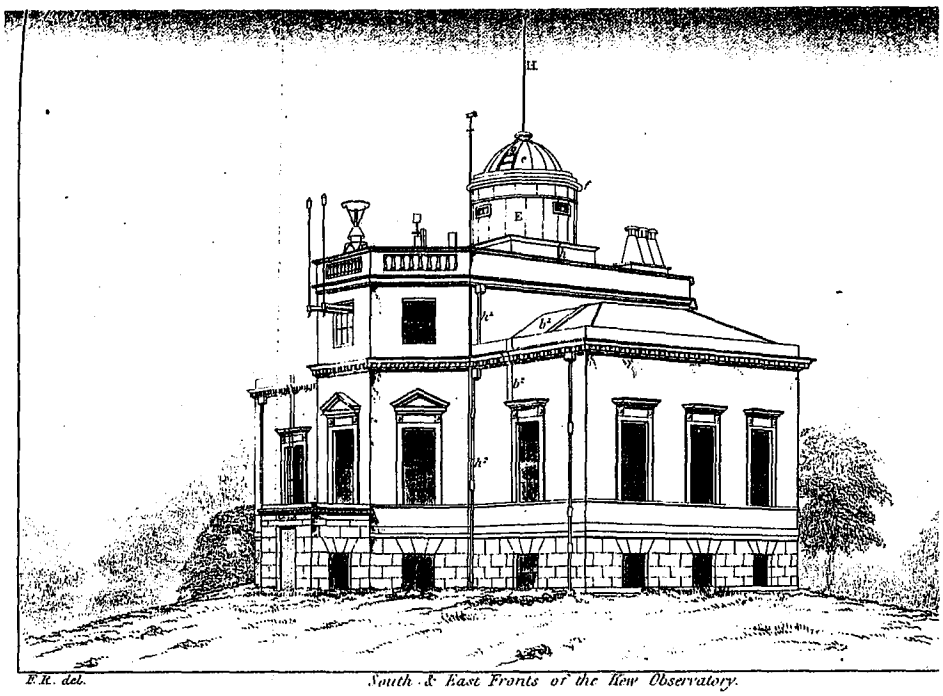


Fig. 1 *Kew as BA Observatory.*

The aged and conservative Council of the Royal Society dithered and at the last moment withdrew their interest in Kew Observatory. Some young Fellows on the Physical Committee, who were also members of the recently founded, active and inclusive British Association for the Advancement of Science persuaded the Council of the BA to take an interest. Within two months the matter was sealed - though it was another month before the General Committee of the BA ratified what had been done in their name without even making a projection of future financial costs! [5] The 1842 Presidential Address to the BA announced to the assembled delegates -

> the important accession to the means of this Society of .... a place for deposit, regulation and comparison of instruments, and for many more purposes 6

Taking on Kew Observatory (Fig. 1) in 1842 was quite atypical of the BA. Its funds were limited. As a matter of policy they were restricted to pump-priming, short-term research and encouraging co-operative ventures. In 1845 the General Committee asked the Council to reconsider operating the Observatory, and the situation was reviewed in 1848 and 1849. In the intervening years the BA Kew Physical Observatory developed a well-focussed mission, and in particular established a reputation for meteorological investigation, with special reference to the development of self-registering instruments, and investigation of atmospheric electricity. Luminaries like Sir John Herschel, Professor Charles Wheatstone and Edward Sabine, who as Fellows of the Royal Society had drafted the Kew proposals for the Physical Committee, were also influential members of the BA. They took an active interest in developments at Kew, though the moving spirit in the first decade was Francis Ronalds FRS, Honorary Superintendent from 1843 to 1851. The initial research programme reflected his particular interests and the desire of the BA to encourage the collection of comparable meteorological and magnetic data across the United Kingdom and the known world.[7] In this context Ronalds reported to the 1848 meeting that the East India Company had commissioned copies of the apparatus for recording magneto-electrical phenomena, for shipment to their Colaba Observatory, Bombay.[8] The following year a horizontal force magnetograph on the Kew pattern was tested before being sent to the Observatory at Toronto, for whom a vertical-force magnetograph was under construction. Closer to home, it was also reported that Stoneyhurst College, Lancashire, had drawn-up plans for an 'electric and magnetic observatory', and that the Director of Madrid Observatory had made a visit to discuss setting-up instruments similar to those in use at Kew.[9]

Ronalds' work at Kew was totally voluntary. Few of his contemporaries were free to demonstrate their commitment to science on such a scale. In August 1850 John Welsh

was employed at Kew as a paid assistant. When Ronalds retired to the continent, Welsh became the salaried Superintendent in 1852. Balfour Stewart succeeded to that post in May 1859. Welsh took a particular interest in the making of standard thermometers for scientists and the trade, and the verification of thermometers and barometers, for which a new and significant demand came from the Admiralty and the Board of Trade, anxious to equip both naval and mercantile ships with the means of making good meteorological records during their voyages. He also built on Ronalds' work on instrument design, especially the use of photographic self-recording methods. Stewart, in turn, built on Welsh's work, and over the next decade took on the verification of other instruments, in particular those used for magnetic work. Both followed Ronalds' example in acting as an intermediary for overseas customers wanting London made meteorological and magnetic instruments.

After the death of Admiral Fitzroy in 1865 there was a reorganization of the Meteorological Department of the Board of Trade, which he had headed. The impact on Kew was twofold. From 1867 the Board of Trade's meteorological activities were supervised by a committee, its membership nominated by the Royal Society. Baflour Stewart was appointed Secretary, whilst continuing as Superintendent of the Kew Observatory. Kew became the Central Observatory of the Meteorological Department with additional responsibility for the instruments used at the various substations in the British Isles. Both Stewart and the Observatory now served two masters, a situation ameliorated by cross-membership between the BA Kew Committee and the new Board of Trade Meteorological Committee. The annual BA listing of 'Grants for Scientific Purposes' show that Kew made significant call on annual research expenditure - £183 of £1,565 (12%) in 1843, £255 of £346 (74%) in 1850, £500 of £1,241 (21%) in 1869 and £600 of £1,572 (38%) in 1870. But the financial future looked bleak - the Observatory accounts for the year ending mid September 1870 show a deficit of just over £200, met by the Committee chairman from his private fortune.[10] During 1870 the British Association informed the Royal Society, who had routinely assisted funding meteorological, magnetic and other activities at Kew from the mid 1850s, that as from September 1872 they would withdraw from the Observatory in their favour. Stewart, uncertain of his own future, took a teaching post at Owens College, Manchester. In the event, the Royal Society took over Kew on 1 August 1871. A significant portion of the funding gap was filled by the long-standing BA Kew Committee chairman, J.P. Gassiot FRS, who lodged £10,000 with the Royal Society to fund an endowment to assist

> in carrying on and continuing magnetical and meteorological observations with self-recording instruments, and any other physical investigations as may from time to time be found practical and desirable'.[11]

Nevertheless it was necessary to reduce costs and Robert Beckley, who for 18 years had provided key technical support as 'mechanician' at a salary that had risen to £150 pa., was given notice - 'such an official being no longer required' [12] - a judgment somewhat undermined by the comment in annual reports from 1877 that

> the funds of the [Kew] Committee do not at present allow of the employment of a mechanical assistant, although one is much needed'. 13

Under the management of the Royal Society testing and verification of instruments continued at Kew, with both the numbers and the range of instruments increasing. From the mid 1880s watches and chronometers were also tested and verified for the trade. Both under the BA and the Royal Society, Kew continued to benefit from the voluntary expertise of scientists who were willing and able to undertake research and development activities, sometimes funded by special grants, sometimes at their own expense.

In 1897 Lord Rayleigh chaired a government enquiry established:

> to consider and report upon the desirability of establishing a National Physical Laboratory for the testing and verification of instruments for the construction and preservation of standards of measurement, and for the systematic determination of physical constant and numerical data for scientific and industrial purposes; and to report whether the work of such an institution, if established, could be associated with any testing or standardising work already performed wholly or partly at the public cost.

The Kew Committee Chairman and the Superintendent of the Observatory gave evidence, and official visits were made to the Observatory. The upshot was that from 1900 Kew became part of the newly established government funded National Physical Laboratory.[14]

Instrument Verification at Kew

In 1851 the Council of the BA allotted an additional £150 to the Kew Committee for the express purpose of 'the construction and verification of standard meteorological instruments'. Apparatus for examining and calibrating thermometer tubes, by Regnault, together with a Ramsden-type linear dividing engine, by Perraux, had been ordered from Paris, apparently in anticipation of funding, by J.P. Gassiot, who became Chairman in 1853. By July 1851 six standard thermometers had been made - the work largely undertaken by Welsh.[15] Gassiot and Welsh implemented the BA Council direction to supply standard thermometers to members of the British Association and Fellows of the Royal Society at £1 each. The remit was broadened to allow the presentation of standard mercurial thermometers to selected instrument makers, and sales to any Government Department and the East India Company. Here was a way of raising the quality of temperature observations made by savants, and the quality of commercial instruments. London makers, Adie, Barrow, Watkins & Hill, Newman and Simms were presented with a Kew Standard thermometer. Work was also put in hand to design and construct a standard barometer.[16]

The 1853 *BA Report* noted that 70 Kew Standard thermometers had been supplied, and that 'in order to facilitate the comparison' any instrument maker would be supplied on request at the cost of £1 - with the Observatory willing to examine commercially made instruments, and provide a table of errors. In terms of scale, this activity was rapidly dwarfed by a request from the Hydrographer for the Navy for advice as to the best form of thermometer to be supplied for shipboard meteorological use.[17] Welsh and his colleagues developed a design. Copies and a specification were given to selected London makers, together with an invitation to quote for manufacture and supply. Early next year the Smithsonian Institution in Washington asked about barometers and thermometers for shipboard meteorological work including measurement of sea water temperature. Shortly afterwards the Board of Trade required similar assistance for the British merchant marine. By this time, prototype marine barometers made by Patrick Adie of London to Welsh's specifications were being prepared for sea trials. By mid 1854 the scale of involvement had become apparent and the Kew Committee realized that they had to make their position clear. With the exception of their Standard Thermometers, they were not manufacturers - their role was to ensure quality. They would advise on and specify designs, nominate manufactures and negotiate prices. They would test and certify finished products, but contracts would be between client and instrument-maker, the cost of verification at Kew being included in the price. Following responses from selected members of the London trade L.P. Casella and Negretti & Zambra were nominated for the supply of thermometers - at a price not exceeding 6s, to which 1s would be added for verification. Adie was nominated for the supply of marine barometers, with a suggested price of £3.5s 6d, plus 10s for verification. The level of immediate verification activity can be seen by the fact that when the Report was written in mid 1854, Kew had in the course of verification 1000 thermometers and 50 barometers for the US Navy and 500 thermometers and 60 barometers for the Board of Trade.[18]

In successive annual reports to the BA, the Kew Committee record the work of verification - and the income generated by it.

Following the impetus of large official orders from the UK and American governments, the trade rapidly took to using Kew to verify barometers and thermometers prior to sale - with 'opticians', rather than the Admiralty or the Board of Trade accounted for more than half of the annual earnings from verification in 7 of the 17 accounting periods to 1870/71. Either customers for thermometers and barometers were requiring that they purchased instruments whose quality had been verified by Kew, or makers saw this verification as assisting sales. At the same time, Gassiot exerted pressure on manufacturers, commenting adversely in 1855 on the mechanical construction of thermometers made by Casella and Negretti & Zambra, and adjusting the contract specification to obtain the required improvement. The hydrometers made by Adie and Negretti & Zambra also came in for criticism, whilst Casella's were praised. Of Adie's marine barometers Gassiot commented 'they continue to improve in quality and regularity as the maker become more familiar with the work'.

Balfour Stewart, appointed Superintendent in 1859, continued the testing of meteorological instruments. He had inherited from his predecessor the beginnings of a programme for the commissioning and testing of magnetic instruments for other observatories. The BA were pressing the Government to support the establishment of a network of stations at home and in the colonies, and in anticipation had commissioned a set of self-recording magnetographs, testing them at Kew in a temporary wooden house lent by the Ordnance Office, for it was largely officers and men of the Royal Artillery, trained at Woolwich, who initially staffed these colonial observatories. In the event, the Dutch government purchased that set for Java and an official came to Kew to learn how to use them. So far as verification is concerned the years 1859/60 and 1860/61 mark a step change in activities at Kew, with work on verifying magnetic instruments of various sorts becoming quite significant. It would appear that in their anxiety to ensure that magnetic instruments were properly verified, Kew had not really considered the cost implications - it was only through the good offices of the Royal Society that they were reimbursed for work on the sets for Java, Washington USA, and Coimbra University Observatory. The cost was £90 - as against the £81.5s of income generated that year through the verification of 150 barometers and 660 thermometers. These figures indicate how much more demanding was the work of verifying magnetic apparatus. In future £30 was to be added to the cost of each set of magnetographs to meet the cost of verification. Other magnetic equipment was less expensive to verify, but in the years 1860 to 1879 when the accounts separate verification fees for meteorological instruments from those for magnetic instruments, it is quite clear that a small through put of such instruments had a significant impact on total earnings, and that the work load was quite erratic.

> A system has also been organized for etching a "Hall-mark," as in the annexed figure, upon all Thermometers which have been verified. A pantagraph has been purchased for the purpose of engraving this mark and a register number upon the instruments.

Fig. 2 *Kew's hallmark for thermometers, 1889.*

The way in which the annual reports and accounts for Kew are presented, indicate how the organization wanted to be perceived. Kew was proud of its work in verification. It enumerated the work, but felt little need to justify it. In the changing presentation of the summary annual accounts, financial control over the various activities undertaken is increasingly demonstrated. From 1872, under the Royal Society, the published accounts show not just income expended and received, but also liabilities, and the value of accounts rendered but awaiting payment. From 1867 duality of control meant presentation of reports in two parts - 'Work done by Kew Observatory under the direction of the British Association' and 'Work done at Kew as the Central Observatory of the Meteorological Committee'. The BA Kew Committee accounts show charges for services and the temporary secondment of staff to the government funded Meteorological Committee. For many years Royal Society management continued this duality of reporting. It also provided figures of total income and expenditure for the commissioning of instruments for overseas scientists and institutions, a practice foreshadowed by the BA in 1870/71 when the profit from commissions was first recorded. That there were losses in six of the 18 accounting years between 1871 and 1888 (£75 loss on a turnover of £510 in 1875/6 was the worst) was not a matter requiring comment. Commissions only exceeded £700 pa. twice, (1877/8 and 1883/4) and averaged about £420 pa. In general, after 1884 there is a downward trend in the total value of commissions, and from 1889 healthier surpluses. However, in 1891 accounting practice apportioned 'incidental expenses' to various activities, followed in 1895 by an allotment of central administrative costs across all Kew activities. Commercially this should have led to a significant increase in the charge for handling the orders of overseas clients, or closure of the activity - for the imposition of central administrative charges implied significant losses in each of the following five years. That there was no comment on this situation implies that the Royal Society appreciated that such work should be measured not merely as an actuarial balance of income over expenditure. They appreciated the intangible values accruing to the scientific community as a whole, not attempting to recover the full costs of assisting colleagues across the world to acquire instruments whose performance could be trusted, and whose observations would be available to all. Yet, it could be that growing awareness of the financial costs of scientific altruism may have been a factor in the Royal Society willingly passing on total responsibility for Kew Observatory to a new organization funded directly by the government - the National Physical Laboratory.

Concern for the quality of the results of meteorological and magnetic observation is also illustrated by the provision by Kew of training in the use of instruments. Starting in Ronalds' period as Honorary Superintendent through to the end of the century, the training of observers became an integral part of the service. In 1850/1 Lieut. Fergusson of the Indian Navy was given instruction in the use of self-registering instruments and eye observations of atmospheric electricity, and J.A.Broun, Director designate at Trivandrum Observatory (southern India) was instructed in all Kew procedures. In 1871/2 Prof. H.F. Blanford, Meteorological Reporter to the government of Bengal, and the Bishop of Rupert's Land (northern Canada) were both given instruction in meteorological work, whilst C. Carpmael of Toronto Observatory was taught both magnetical and meteorological work, and officers of the North-American Boundary Commission, and the oceanographic expedition ship *HMS Challenger* were instructed in magnetic work. A decade later W.L. Dallas was given instruction in the use of all meteorological instruments prior to taking up post as Scientific Assistant to the Meteorological Reporter of India, whilst in 1899 the use of magnetic instruments was taught to Messers Colbeck and Bernacchi, observers for the Borchgrevink antarctic expedition.

In 1876, G.M. Whipple was promoted from First Assistant to Superintendent, in succession to Samuel Jeffrey. That year Kew acquired equipment to 'hallmark' and number verified thermometers. The 1878/9 report, records that the mark was not being sought by makers, so the cost was buried within a revised scale of charges. As from January 1879 the KO monogram and a reg-

istered number were etched on all thermometers verified at Kew. The purchase of further equipment is recorded in 1889 so that the KO 'hallmark' (Fig. 2) and a reference number could be engraved on other verified instruments, beginning with artificial horizons, telescopes and barometers made for the Navy. The idea was not novel, gold and silver had been so marked for centuries, whilst in 1854 the Board of Trade, in correspondence with Kew had requested that verified instruments 'bear upon them a stamp indicating that they have undergone an inspection and been compared with an approved standard'. Whipple was also responsible for putting in place the Committee's 1875 idea of a London depot for the receipt of instruments to be verified, making the logistics of verification much easier for the London trade.

The 1883 annual report is marked by the inclusion within the figures for instruments verified, of the failure rate - at least for clinical and meteorological thermometers, with some other major classes included from 1893. Presumably such figures could be extracted from archived records, but in the printed reports they appeared rarely, in 1869, for example 27 of 157 barometers were rejected, and 24 of 1153 thermometers, whilst in 1870 30 of 150 barometers were rejected. The failures for clinical and meteorological thermometers are normally under 1%. The figures for other cited instruments cover much shorter periods - eight for telescopes, four for sextants, three for binoculars - too short to demonstrate trends. Indeed the common factor appears to be that the poor performance of the cited instruments (a quarter of all telescopes failing in 1892, and one in five sextants in 1892 and 1895) allowed the publication of a low figure of failure for all other instruments, excepting thermometers and barometers.

Overall, the changing content and level of detail that occurs over the half century of published records of instrument verification at Kew demonstrates a growing appreciation of showing the costs of the various activities undertaken. However, the subtext of those reports indicates that the financial analysis was intended to informing judgments about scientific priorities. What is implicit over both commissioning and verification is that Kew was ensuring that the end user was not at the mercy of the instrument maker over quality. That the trade may not have been totally happy with an evaluation process over which it had no control, may be reflected in the fact that the National Physical Laboratory had a trade representative on its governing body.

The Verified Instruments

The level of detail given in Annual Reports, varied over time, reflecting the changing priorities at Kew, and the interests of the British Association and the Royal Society.

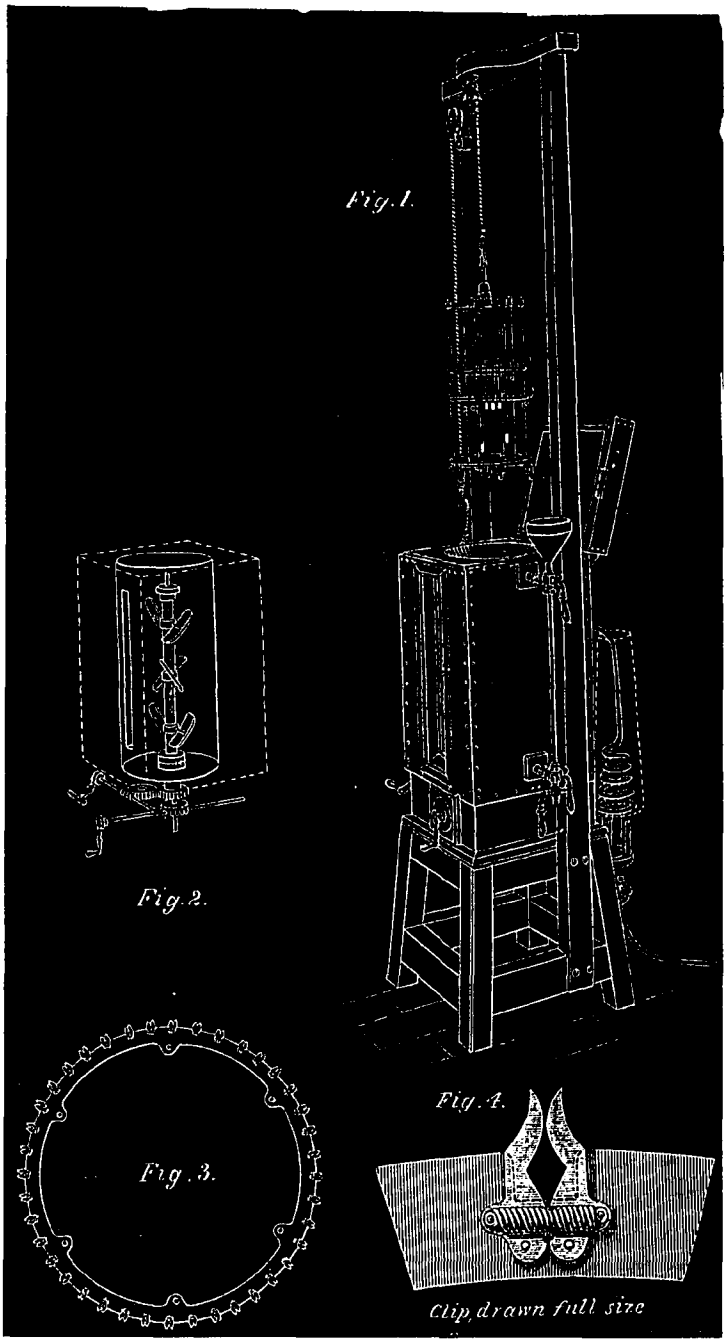
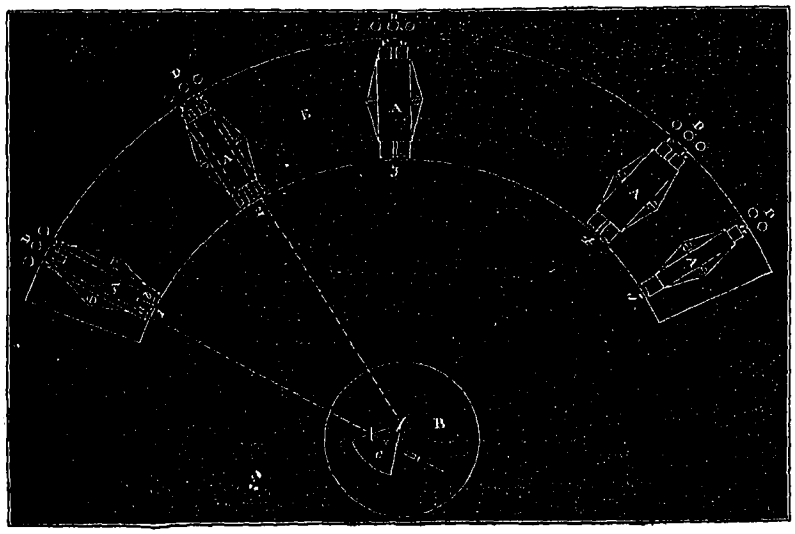


Fig. 3 *Galton's thermometer testing apparatus, at Kew, 1875.*

New testing equipment was developed from time to time, though the availability of a test did not necessarily mean that the trade responded by sending instruments to Kew. It was still essential for the customer to require and pay for independent verification. The initial impact of large orders from the Admiralty, the Board of Trade and the government of the United States placed a strain on Kew in the early years of the 1850s. Once those orders had been processed, work from the trade began to grow, along with smaller orders from the Admiralty and the Board. Staff numbers grew and testing equipment was acquired.[19] From the 1870s the range of devices tested grew - for example rain gauges and measuring glasses from 1872, sunshine recorders from 1885. Numbers alone can mislead; the hydrometers verified in large numbers in the 1850s (1269 in 1854/5, 751 in 1856/7) were for reading the specific gravity of sea water, but the revival in test numbers, which reached a secondary peak of 1,161 in 1884, was largely due to the submission of Sikes hydrometers, used for testing alcohol strength and assessing duty in brewing and distilling industries.[20] Similarly, until the 1890s the compasses verified at Kew were mostly portable azimuth instruments used by explorers and travellers for survey purposes, with the sudden and short-term increase in numbers in 1895 apparently due to the decision to test



A. Double collimators.
B. Table for holding sextants.
C. Sextant.
D. Candles for illuminating wires.
E. Slate to which collimators are bolted.
F & G. Wires in collimators.

Fig. 4 *Plan of Cooke's apparatus for verifying sextants at Kew Observatory, 1865.*

marine compasses, using test equipment similar to that used by the Admiralty at Deptford.[21] The 1872 report notes that anemometers of various designs had been tested, but that the sylvan surroundings of the observatory made testing somewhat impracticable. Additional land was rented in Richmond Park the following year but the exposure was insufficient for adequate field trials. During 1874 experiments took place at the Crystal Palace, using a steam driven blower, which allowed wind speeds of up to 30 mph to be replicated. However, the cost of acquiring a blower for Kew was considered prohibitive. The topic was returned to in 1880 whilst in 1889 a whirling apparatus was constructed in-house to permit the examination of air meters, as used to measure air currents in mine workings. Nevertheless there remained difficulties in reconciling the performance of different designs of instruments.[22] The numbers tested were, however, relatively small - 24 anemometers and 15 air meters verified in 1893, being by far the largest number processed.

Kew Standard Thermometers

Kew's attempt to raise the quality of meteorological instrumentation began with the manufacture and supply of standard thermometers.[23] The numbers issued annually were small - the 70 supplied in 1852 was by far the largest over the next half century. Indeed, despite extensive publicity, the Committee recorded their disappointment at the take-up in their 1852-3 report, when only 24 had been supplied. Furthermore, no more were requested until 1860/1861, and even then the number provided per year, only exceeded a dozen on seven occasions up to the end of the century.The small numbers of standard thermometers made at Kew was in no way a reflection of the high reputation in which they were held, underlined by two quite separate and independent tests published in the early 1880s.[24]

Thermometers

In 1853-4 181 thermometers were verified, of which 165 were for normal meteorological use, 6 were boiling point standards - intended for ascertaining altitude[25], and 10 ground thermometers. For the next 15 years only gross totals were reported - averaging over 760 a year, a figure skewed by the 2,520 verified in 1854-5. Even where detail is lacking, the trends are revealing. The US Government, the Admiralty and the Board of Trade, speedily ensured that naval and merchant vessels were all equipped. Indeed, such was the enthusiasm of the Board of Trade for equipping the merchant marine, that copies of the Kew verifying apparatus for thermometers and barometers were commissioned by the Board and supplied to Liverpool Observatory in 1855 - the Admiralty signalling their intention to provide similar apparatus for Portsmouth and Plymouth. BA Committee reports are silent as to the eventual use (if any) of such equipment. Kew's expertise in thermometer verification was acknowledged in 1880 when a visitor from Yale made a special visit, the American College having decided to establish a similar verification service.26 Initial testing method for thermometers was time consuming, difficult to control and required subjective judgment from the operator. Francis Galton FRS, who developed a new form of thermometer testing apparatus for Kew in 1875 (Fig. 3), described it as 'of the crudest character'. The new apparatus, designed with the advice of Warren de la Rue FRS and the technical assistance of the instrument-maker R. Munro, allowed batches of 40 thermometers to be tested together.27During 1867 apparatus for liquefying carbonic acid was purchased with funds from the Royal Society. The intention of using it to verify thermometers at very low temperatures was realized in 1874, but again the numbers were never large, the 272 and 221 in 1873-4 and 1874-5 being the only years when the numbers tested exceeded 200. 28

In 1870-1, when the detail of types reappear in the record, just under a third (31%) of the total is accounted for by clinical thermometers - a proportion that continued to increase - 69% in 1878/9, 79% in 1888/9 and 83% in 1899. The number of clinical thermometers verified was 417 in 1870-1, 3,405 in 1878-9, 10,016 in 1888-9 and 16,020 in 1899, peaking at 17,962 the previous year. Clinical thermometers overtook and then eclipsed the number of meteorological thermometers verified - 876, 1,286, 1,910 and 2,892 for the years cited, with the peak at 4,901 in 1890.

Barometers

In 1853-4 23 barometers were verified - and that number comprised 9 aneroids, 8 standard, and 6 mountain instruments. For the next 15 years no detail is provided, only the gross total tested using apparatus designed and made at Kew for that purpose.[29] Under the BA, barometer verification peaked at 257 instruments in 1854-5, with the annual average number per year only 142. In the first 8 years of Royal Society management that average grew to 192 per annum, to 228 over the next decade and 320 the final decade of the century. A significant proportion of this growth is attributable to the numbers of aneroid barometers verified, rather than mercury based marine, standard and station barometers that meteorologists preferred. Kew had tested aneroids in 1853 when 9 instruments had been sent by the Berlin instrument makers Schlagintweit. It does not appear to have verified them routinely until after the 1867 request from the Board of Trade Meteorological Committee to develop a test. Robert Beckley, the Kew mechanic, designed and built a suitable test rig, and aneroids from the 'best-known makers' were examined. It was concluded that

> aneroids cannot be considered equal in accuracy to standard Barometers, yet the best constructed aneroids, within certain limits, give reliable results.30

This prejudice remained, with little enthusiasm for Goldschmid type of aneroids submitted for test by Hottinger of Zurich in 1878[31], whilst a pair of highly sensitive aneroids made by Richard Frères of Paris were dismissed in 1887 as 'liable to the same errors as the common aneroid'. From 1894 there were further investigations, but Charles Chree, who had succeeded Whipple as Superintendent in 1892, opened

his report:

> The ordinary aneroid barometer is an instrument whose chief recommendations are its portability and the ease by which it can be used by travellers. It is essentially a field instrument and it would be a waste of time to treat it as if intended for the laboratory.[32]

Magnetic Instruments

As Reynolds' work at Kew became known, others wanted similar equipment. His 1848 report records that the East India Company Observatory at Colaba, near Bombay, had commissioned a copy of the apparatus for measuring and recording atmospheric electricity.Toronto, the most active of the Board of Trade colonial observatories, staffed by military engineers from the Ordnance Office, was supplied with the self recording magnetographs in 1849 (horizontal force) and 1850 (vertical force). From such small beginnings Kew moved into acting as both verifier and intermediary in equipping magnetic observatories across the world, though it was not until 1860-61 that the activity became relatively routine with the newly developed self-recording magnetographs, dip-circles and unifilar magnetometers being verified for use in Java, and Coimbra, and for the United States Coastal Survey.The Royal Society reports are more systematic in recording when Kew acted as an agent, so that from 1871-2 the scale of commissioning activity can be seen both in the summary annual accounts and in the detailed tabulation of magnetic apparatus. It is a measure of the significance that Kew attached to its activities as a central repository of expertise on geomagnetic instrumentation, and a regulator of performance, that into the 1890s the published annual reports detail the recipients for magnetic instruments verified, irrespective of whether they were commissioned through the Observatory, or brought in for testing by the trade. The data is collected in **Appendix 1** and summarized in the table. The effort that Kew put into testing magnetic instruments is a measure of scientific need that results garnered from stations across the world would be reliable. However, in comparison with thermometers and barometers the numbers of such instruments tested were very small as is illustrated by the summary table:

Instrument Type	1851-61	1862-71	1872-9	1880-89	1890-99
Magnetograph	3	10	10	4	-
Unifilar	10	15	25	39	40
Dip-circle	10	23	42	38	-
Inclinometer	-	-	-	23	44
Vertical Force	-	-	-	-	50

Surveying and Optical Instruments

At the 1858 BA meeting the General Committee asked the Kew Committee to take an interest in the verification of portable instruments for 'Government Expeditions' and 'Scientific Travellers', hoping that their achievements with meteorological and magnetic instruments could also be turned to the assistance of 'Geographical Science'. Gassiot's response was acceptance of the principle but a polite reminder to the General Committee that the Observatory was already over stretched and that it was unwise to take on further responsibilities which could undermine its reputation. Nevertheless something was done - Francis Galton FRS, working as an unpaid supernumerary, developed and funded a test rig for sextants. The method was weather dependent, required bright sunshine, and the test took two hours per instrument. By 1865 the Royal Society had funded an indoor test rig designed and made by Thomas Cooke (Fig. 4) of York. A scale of charges was issued and eight sextants recorded as having been verified. With this apparatus installed Gassiot hoped

> that the Observatory will become a place where quadrants and sextants are verified with great facility and where scientific travellers or officers of Her Majesty's service may receive instruction in the use of geographical instruments'.33

Help had earlier been given to explorers - in 1857-8 a set of magnetical instruments had been verified for Livingstone's Zambesi expedition, and two of his party trained to use them, and in 1860/1 a unifilar magnetometer, dip circle and an azimuth compass were verified for 'Dr Livingstone, Africa' - the records also note two azimuth compasses verified in 1877-8 for H.M. Stanley. Perhaps because the Cooke sextant testing equipment had teething problems, initial take-up was small - only 35 instruments in the first decade, and a mere 14 in the next ten years. From 1881 numbers began to rise significantly, following changes to the apparatus during 1880, and the installation of equipment that permitted separate testing of index and horizon mirrors and the shades[34], together with changes in the test specification. In 1885, 130 sextants were tested, together with 235 shade glasses and 74 index or horizon mirrors, a demand that lead to the relocation of the test apparatus in a room dedicated for that purpose. The apparatus was used that year to graduate some Nordenfelt range-finders, made in London by Casella, and adapted in 1887 so that it could be used to test other designs - 17 being recorded as verified, but such devices do not reappear in the published record. In 1889 the number of sextants tested had risen to 292, and continued to rise steadily, reaching 876 in 1899.The publication of the failure rate for sextants for the years 1892 to 1895 - 19%, 21%, 13% and 16% is an indication of the importance of independent testing in ensuring that the trade met designated performance standards.

The 1887 Report records development work on a test for evaluating telescopes, based on the procedure used at Greenwich Observatory for naval telescopes. By the following year Kew announced that it would undertake performance tests for trade and public alike, charging 2*s* 6*d* for marine telescopes and binoculars, and 1*s* 6*d* for opera glasses and pocket telescopes. From 1889 it was under contract to the Admiralty to test telescopes and binoculars ordered by the Navy, and 440 were tested that year, with the numbers rising to 404 binoculars and 561 telescopes in 1899. In 1890 Kew undertook special examination of a gun director telescope and a new pattern telescope for the Admiralty, whilst in 1892 a batch of 72 telescopes for issue to field artillery officers, was tested for the Royal Engineers. The publication of failure rates for telescopes from 1892 and for binoculars from 1897, suggests that for such instruments, quality control was a real issue - 24% of telescopes failed in 1892, and although the figure had dropped to 2% in 1895, the improvement was not maintained, rising to around 9% in each of the last three years of the century.

Miscellaneous Instruments

Kew's reputation in instrumentation verification led to requests to undertake a variety of one off tests. It became the obvious place for government agencies, learned societies and the trade to turn to for disinterested evaluation, and Kew appears to have been happy to oblige, even in areas that were not related to its expertise in meteorology and magnetism. The 1864 report records the verification of a set of weights, a standard scale and a volume measure, and in 1866-7 that two standard yards had been compared for the trade. 'A number of [unspecified] instruments of various kinds' were verified for the Standards Department, Inland Revenue Office and the Ordnance Department in 1875-6 and 1876-7, and in 1888-9 33 standard measure of length for the War Office. During the next year special examination was made of 'various instruments for the Anglo-German Boundary Commission on the Gold Coast', whilst the Admiralty asked for reports on a gun-director telescope and a new pattern

Officer's telescope. Watkins, the London instrument makers, commissioned reports on two newly designed instruments, a clinometer and an aneroid barometer. In 1879 and 1880 Kew hosted an experimental rig designed by and for the Sanitary Institute of Great Britain to test the efficiency of various designs of ventilating cowls. In contrast in 1888 it decided not to become involved in the examination of ship's lights for the merchant marine. That year the Camera Club, backed by two members of the Committee suggested it investigated a quality test for camera lenses. The complicating factor was that the Camera Club envisaged a relatively cheap test. By 1890 a compromise had been proposed, with a cheap and cursory trial or a more expensive but detailed. Testing began in 1891 but numbers were very small in the first instance, despite the wide publicity given to the new test procedures developed by Leonard Darwin.[35] In the next few years, the tests were progressively broadened and improved, and in 1899 the numbers examined rose by a factor of ten, but at 160 represented only a tiny fraction of the potential market.

Note on Sources Material

This paper is based largely on working through the published annual reports of the Kew Committee. Under the British Association for the Advancement of Science, these reports appear in the annual BA meeting reports, normally as part of the reports of the General Committee and the Council of the Association. The accounting period for the BA reports runs from one annual meeting to the next, so that the 'year' may vary by over a month. Under the Royal Society, the new Committee reports appear vicariously within the published *Proceedings of the Royal Society*. The accounting period was initially from November through to the following October, give or take a few days, but in 1890-91 a 14 month year was used, and after that the calendar year and accounting year coincided. To minimize footnotes, I have not usually given references when citing the report for a particular year in the text.

I have from time to time come across the occasional instrument with KO hallmark and numbers, or with a Kew verification certificate in the box. Indeed it was seeing such instruments in the 1960s that first roused my interest in Kew's activities in this area. Alas, I failed to record any details!

Notes and References

1. 'Report of the Committee appointed by the Royal Society to consider the best method of adjusting the fixed points of thermometers; and of the precautions necessary to be used in making experiments with those instruments', *Phil. Trans. R. Soc. Lond.*, 67 (1777), pp. 816-857. See also W.E.K. Middleton, *The History of the Thermometer and its Uses in Meteorology*, (Baltimore, 1966), p.127.

2. J.D. Forbes, 'Report upon recent progress and the present state of meteorology', *Report of the British Association for the Advancement of Science*, (1832), pp. 196-258. For the limited progress, made in the next decade see J.D. Forbes, 'Supplementary Report on Meteorology', *BA Report 1840*, pp. 37-156.

3. A.Q. Morton and J. Wess, *Public & Private Science, the King George III Collection* (Oxford, 1993).

4. Report read 10 February 1842, printed in R.H. Scott, 'The History of Kew Observatory', *Proceedings of the Royal Society of London*, 39 (1886), pp. 48-9.

5. Scott, (note 4), pp. 47-52. See also J. Morrell and A. Thackray, *Gentlemen of Science: the early years of the British Association for the Advancement of Science* (Oxford, 1981), pp. 348-9, 522-3.

6. *BA Report 1842*, p. xxv.

7. For Ronalds' contribution see the annual repots of the 'Kew Committee' especially *BA Report 1844*, pp. 120-142, *BA Report 1851*, pp. 335-370. For the BA's national and international activities in encouraging co-operative, comparable research in meteorology see the seven 'Reports of the Committee ... for superintending the scientific co-operation ... in the system of simultaneous observations in terrestrial magnetism and meteorology', in *BA Report 1839*, pp. 31-43; *1840*, pp. 427-432; *1841*, pp. 38-41; *1842*, pp. 1-11; *1843*, pp. 54-60; *1844*, pp. 143-155; *1845*, pp. 1-72.

8. *BA Report 1848*, p. xviii. After the demise of the East India Company, Colaba was funded by British Government, through the India Office.

9. *BA Report 1849*, pp. 83-6. The Madrid apparatus reported as 'now constructing', *BA Report 1851*, p. 339.

10. Figures from cumulative 'General Statements of Sums ... Grants for Scientific Purposes', *BA Report 1873*, pp. lxii-lxviii. See also *BA Report 1870*, p. lvii.

11. Scott, (note 4), p. 64.

12. 'Report of the Kew Committee .... ending 31 October 1872', *Proc. Roy. Soc. Lond.* 21 (1873), p. 40.

13. *Proc. Roy. Soc. Lond.*, 26 (1878), p. 467.

14. *Proc. Roy. Soc. Lond.*, 63 (1898), p. 170; 65 (1900), p. 12; 66 (1900), pp. 349-350; see also E.C. Pyatt, *The National Physical Laboratory, a history* (Bristol [1893]); E. Magnello and G. Gooday, *A Century of Measurement: an illustrated history of the National Physical Laboratory*, (Bath, 2000).

15. *BA Report 1851*, pp. xxviii, 346, 364.

16. *BA Report 1852*, p. xxviii.

17. *BA Report 1853*, pp. xxix-xxxi.

18. *BA Report 1854*, pp. xxvi-xliii.

19. J. Welsh, 'Report of the general process adopted in graduating and comparing the standard meteorological instruments for the Kew Observatory', *Proc. R. Soc. Lond.*, 6 (1852), pp. 178-183.

20. 'Kew Report 1884', *Proc. R. Soc. Lond.*, 37 (1884), p. 468; see also 'Kew Report 1886', *Proc. R. Soc. Lond.*, 41 (1887), p. 407 and 43 (1888), p. 218.

21. 'Kew Report 1896', *Proc. R. Soc. Lond.*, 59 (1897), p. 103.

22. G.M. Whipple and W.H. Dines, 'Report of the Wind Force Committee on experiments with anemometers', *Quarterly Journal of the Royal Meteorological Society*, 14 (1888), pp. 253-263; G.M. Whipple, 'Results of a comparison of Richards anemo-cinemographe with the standard Beckley anemograph at the Kew Observatory', *Q. Jnl. R. Met. Soc.*, 18 (1892), pp. 257-262; W.H. Dines, 'Anemometer comparisons', *Q. Jnl. R. Met. Soc.*, 18 (1892), pp. 165-185; C. Chree, 'Contribution to the theory of the Robinson cup anemometer', *Philosophical Magazine*, 40 5th series (1895), pp. 63-90.

23. J. Welsh, 'On the graduation of standard thermometers at the Kew Observatory', *Proc. R. Soc. Lond.*, 6 (1852), pp. 178-83; shorter version in *BA Report 1853*, pt 2, pp. 34-36.

24. L. Waldo, 'Papers on thermometry from the Whinchester Observatory of Yale College', *American Journal of Science*, 21 3rd series (1881), pp. 57-61, 226-230, 443-453. T.E. Thorpe and A.W. Rucker, 'On the calibration of thermometers by Bessel's method', *BA Report 1881*, pp. 540-541.

25. J. Welsh, 'Instruction for the graduation of Boiling Point thermometers for the measurement of height', *BA Report 1856*, pt 2, p. 49.

26. 'Kew Report 1880', *Proc. R. Soc. Lond.*, 31 (1881), p. 124; see also 'Kew Report 1882', *Proc. R. Soc. Lond.*, 34 (1883), p. 352.

27. F. Galton, 'Description of the process of verifying thermometers at the Kew Observatory', *Phil. Mag.*, 4 5th series (1877), pp. 226-231, and *Proc. R. Soc. Lond.*, 26 (1878), pp. 84-89.

28. R. Addams, 'On the construction of apparatus for solidifying carbonic acid', *BA Report 1838*, pt 2, pp. 70-71. Low temperature thermometers had been produced in 1851/2 see J. Welsh, 'On the graduation of the thermometers for the Arctic Searching Expedition', *Proc. R. Soc. Lond.*, 6 (1852), pp. 183-188.

29. J. Welsh, 'Account of the construction of

a standard barometer, and description of the apparatus and proceeses used in the verification of barometers at the Kew Observatory', *Phil. Trans. R. Soc. Lond.*, 146 (1856), pp. 507-513.

30. *BA Report 1867*, p. lv. See also B. Stewart, 'An account of certain experiments on aneroid barometers made at Kew Observatory at the expense of the Meteorological Committee', *Proc. R.Soc. Lond.*, 16 (1868), pp. 472-480; and *Phil. Mag.*, 37 4th series (1869), pp. 65-76.

31. G.M. Whipple, 'On the results of comparisons of Goldschmid's aneroids', *Q.Jnl. Met. Soc.*, 5 (1879), pp. 189-191.

32. C. Chree, 'Experiments on aneroid barometers at Kew Observatory', *Phil. Trans. R.Soc. Lond.*, 191 series A (1901), pp. 3-58.

33. *BA Report 1859*, p. xliv; *BA Report 1860*, pp. xxxii-xxxiii; *BA Report 1862*, p. xxxvii; *BA Report 1867*, p. lvii; B. Stewart, 'Description of an apparatus for the verification of Sextants designed and constructed by T.Cooke and recently erected at the Kew Observatory', *Proc. R. Soc. Lond.*, 16 (1868), pp. 2- 6.

34. G.M. Whipple, 'Description of an apparatus employed at the Kew Observatory for the examination of the dark glasses and mirrors of sextants', *Proc. Roy. Soc. Lond.*, 35 (1885), pp. 42-44.

35. L. Darwin, 'On the method of examining photographic objectives at the Kew Observatory', *Proc. Roy. Soc. Lond.*, 52 (1893), pp. 2-4, 403-451. L. Darwin, 'Photographic lens testing at Kew', *Photographic Journal*, 17 (1893), pp. 65-77.

Appendix 1

Standard and special Thermometers made, Magnetic and Meteorological instruments (excepting thermometers and barometers) verified at Kew Observatory prior to 1 January 1900

* = commissioned through Kew

1847/48

Bombay, Colaba Observatory - Copy of Kew atmospheric electricity apparatus, by Newman

1848/49

Toronto Observatory, Capt. Lefroy - Magnetograph, Kew pattern horizontal force self-recording type

1849/50

Toronto Observatory, Capt. Lefroy - Magnetograph, Kew pattern vertical force self-recording type

1850/51

Lieut.Cheyne - Portable electrometer for use on Sir E.Belcher's north polar expedition

1851/52

Standard Thermometers x8+ - Toronto Observatory, Cape of Good Hope Observatory, Messers Adie, Barrow, Watkins & Hill, Negretti, Newman, Simms [all instrument makers], also several unnamed persons

East India Company - Set of Meteorological instruments x20

London, Admiralty - Thermometers for low temperature work x14, for arctic expeditions

1852/53

Standard Thermometers x70 - presumably includes 'suitable thermometers for very delicate experimental researches ordered by Prof. J.D.Forbes (Edinburgh) and W.Thomson (Glasgow) the previous year

Madrid, Royal Observatory - Copy of Kew portable Electrical observatory

Trevandrum Observatory, south India - Copy of Kew portable Electrical observatory

Oxford, Radcliffe Observatory, Mr Johnson - Barograph, Kew pattern self-recording type

1853/4

Standard Thermometers x 24

East India Company - Regnault hygrometers x20

1856/57

Austrian Imperial Navy, for use on *Novara* circumnavigation expedition - Unifilar, Fox's circle, Inclinometer, Azimuth compass (lent by RA Woolwich)

Christiana, M.Aansteen - Dip-circle

Lady Franklin's North Polar Expedition - Magnetical instruments [unspecified]. (lent by RA Woolwich) Lisbon, Meteorological Observatory, Dr Pegado - Dip-circle

Toronto Observatory - Unifilar

1857/58

Austrian Government - Dip-circle by Barrow

East India Company - Beckley pattern Kew Anemometer by Adie

London, Meteorological Department, Board of Trade - Beckley pattern Kew Anemometer by Adie x2

Oregon Boundary Commission - Magnetical instruments [unspecified]

Rome, Observatory, Collegio Romano, Rev P.A.Secchi SJ - Unifilar, Bifilar, Dip-circle

Russian Government - Dip-circle by Barrow

Zambesi River Expedition, Dr.Livingston - Magnetical instruments [unspecified]

1858/9

Standard Thermometer - Prof. Kupffer, Director Russian Magnetical & Meteorological Observatories, presented on the occasion of his visit to Kew

Fiji, Colonel Smythe RA - Unifilar, Dip-circle, Azimuth compass - formerly used by Captain Blakiston

Lisbon, Royal Marine Meteorological Observatory, Dr Pegado - Unifilar, Magnet

Rome, Observatory Collegio Romano, Rev P.A.Secchi SJ - Dip-circle

[Woolwich, RA], General Sabine - Magnet x2

Prof. Hansteen - Dip-circle

1859/60

Magnetical instruments [unspecified] - Dr Blaikie, Lieut. Glover, expedition to Africa (lent by RA Woolwich)

Magnetical instruments [unspecified] - Mr Palmer and Lieut. Blakeston RA (lent by RA Woolwich)

Dip-circle repaired by Barrow x2 - General Sabine [RA Woolwich]

1860/1861

Standard Thermometer x7 - Dr Bergsma (Java) x1, Dr Buys Ballot (Utrecht) x1

Dr.Livingstone, Africa - Unifilar, Dip-circle, Azimuth compass

[Batavia] Java Observatory, Dutch Government, Dr.Bergsma - Set of Self-recording Magnetographs with tabulating instrument, Dip-circle x2, Fox's circle, Unifilar, by Jones

Belen Observatory, Jesuits' College, Havana - Set of Differential Magnetic Instruments§, Unifilar. Dip-circle, Differential declinometer§, Alt-azimuth instrument§; [§= formerly belonging to the Makerstoun Magnetic Observatory, near Kelso]

Coimbra University, J.A.da Souza - Set of Self-recording Magnetographs with tabulating instrument, Dip-circle, Unifilar

Ceylon, Mr.Jackson - Unifilar, Dip-circle

London, Astronomer Royal, Greenwich -

Unifilar

Montreal, Dr.Smallwood - Unifilar, Dip-circle

Sydney, Rev.W.Scott,Astronomer for New South Wales - Unifilar, Dip-circle

[Utrecht], Dr Buys Ballot - Unifilar by Jones

[Washington], Dr A.D.Bache, United States Coastal Survey - Set of Self-recording Magnetographs with tabulating instrument, Dip-circle, Unifilar

1861/1862

Unifilar, Bifilar, Dip-circle, Differential declinometer - Lieut.Rokeby, Royal Marines, for use on Ascension Island

Differential declinometer - Mr. Meldrum, Government Observatory, Mauritius

1862/1863

Standard Thermometer x 6 - Mr Kemp, philosophical instrument maker, Edinburgh, x1

Ascension Island - Self recording Kew pattern Anemometer by Adie

Lisbon Meteorological Observatory - Set of self recording Magnetographs by Adie

1863/64

Standard Thermometer x 5

St.Petersburg Central Observatory, Prof. Kupffer - Set of self recording Magnetographs by Adie, Differential vertical force magnetometer by Adie, Barograph, Kew pattern self registering Anemometer

Florence, Prof.Donati - Set of self recording Magnetographs by Adie

Lisbon Observatory - Unifilar, Dip-circle, Self recording Thomson pattern Electrometer

1864/5

Standard thermometer x6

Melbourne Observatory, Mr Ellery - Unifilar, Dip-circle,

Indian Trigonometrical Survey of India, Colonel Walker RE - Unifilar x2, Dip-circle x2 - ,

1865/6

Standard Thermometer x8

Bombay, Colaba Meteorological Observatory - Unifilar, Dip-circle, Anemometer

Cronstadt, Russian Navy Compass Observatory, Cronstadt, Capt.J.Belavenetz - Unifilar, Dip-ircle

India,Trigonometrical Survey, Col. Strange - Unifilar x3, Dip-circle x3

Stoneyhurst College Observatory, Rev.W. Sidegreaves SJ - Set of Self-recording Magnetographs, Barograph

Straits of Magellan survey, HMS *Nassau*, Capt. Mayne - Unifilar, Dip-circle

Utrecht, Dr Buys-Ballot - Declination magnetograph, by Adie

Zanzibar, Dr.Kirk - Unifilar, Dip-circle

1866/7

Standard Thermometer x16 - BoT Meteorological Committee x14

Mauritius Observatory, Mr.Meldrum - Set of Self-recording Magnetographs, by Adie, -

Melbourne Observatory, Government of Victoria, Mr Ellery - Set of Self-recording Magnetographs

1867/68

Colaba Observatory, Bombay, Mr Chambers - Set of self-recording Magnetographs*, Self-recording Barograph & Thermograph*, Tabulating apparatus* for the above, Moffat type Ozonometer*, Thomson electrometer fitted for photographic self registration*, Thermometer testing frame*

Lieut.Elagin, Imperial Russian Navy - Dip-circle, for making observations with it at various European Observatories

London, BoT Meteorological Committee - Set of self-recording Barographs, Thermographs and Anemographs x6, for their 6 outlying Meteorological Observatories,Thermograph Thermometer x24

Mauritius Observatory, through R.& J.Beck, Opticians - Self-recording Barograph & Thermograph

Spitzbergen Expedition, Dr.Lemstrom Physical Observer - Unifilar (lent by General Sabine, RA Woolwich)

Thermograph Thermometer x 8

1868/69

Standard Thermometer x12 - Prof. P.G.Tait (Edinburgh) x9, Stoneyhurst College, Government Standards Commission x2

Mauritius Observatory, Mr.Meldrum - Unifilar, Dip-circle

Melbourne Observatory, Mr.Ellery - Kew pattern Barograph, Kew pattern Thermograph

Nankin, China, Rev.A.M.Colombel SJ - Unifilar, Dip-circle -

Sydney, Mr.Smalley - Kew pattern Barograph

1869/70

Standard Thermometer x21 - Prof. P.G.Tait (Edinburgh) x19, BoT Meteorological Office x2

Batavia, Dr.Bergsma - Dip needle x3

Colaba Observatory, Bombay, Mr.Chambers - Dip needle

Dr.A.B.Meyer, for use in the East Indies - Dip-circle, by Dover

[Hamburg], Dr.Neumayer – Fox's circle (loan)

Kasan University [?Kashan, Persia], Prof. Bolzani - Dip-circle + deflecting cylinder apparatus, by Adie

Lisbon Observatory - Declinometer

Lieut.Elagin, Russian Navy, for use in the *Japanese Seas* - *Unifilar, Dip-circle, latter a* loan, and that formerly used by Captain Haig

[St Petersburg], Russian Central Observatory - Deflection bar

Vienna, Prof.Jelinek - Dip-circle, by Dover -

1870/1871

Standard Thermometer x13 - Owens College Manchester x2, Rugby School, Prof. Harkness Washington Observatory, Dr Draper Central Park Observatory New York x4, Major Norton Chief Signal Office Washington, Mr G.J.Symons, BoT Meteorological Committee x3

Bombay, Colaba Observatory, Mr.Chambers - Dip needle x2, by Dover, Dip needle, by Adie,Thermograph thermometers x3

Bermuda, Major-General Lefroy - Dip-circle (loan)

India - Hodgkinson Actinometers (compared with 2 Royal Society instruments).

Lisbon, Survey Department - Dip-circle by Dover*

Manchester, Owens College - Meteorological Instruments * [unspecified]

New Brunswick, University of Fredricton, Prof. Jack - Standard Barometer by Adie*, Meteorological instruments * [unspecified]

London BoT Meteorological Committee - Thermograph thermometers x3

Vienna, Prof. Jelinek - Dip-circle by Repsold [large 8 needle instrument, reported as 'giving discordant results']

Vienna, K.K.militar-geographisches Insitut - Dip needle, by Dover, Dip-circle by Dover

Washington, Chief Signal Office - Standard Barometer by Adie*

1871/1872

Standard Thermometer* x12 - Meteorological Office, Dominion of Canada x12

Cracow Observatory, Prof.Karlinski - Dip-circle*

HMS *Challenger* - Unifilar, Dip-circle, Fox' s circle - formerly used on HMS *Nassau*

Kasan [?Kashan, Persia] Prof. Smirnov - Unifilar*

Lisbon, Survey Office - Dip-circle*

London,Astronomer Royal - Portable dip instrument (loan).

Manchester, Prof.B.Stewart, Owens College - Unifilar*, Dip-circle*

North-American Boundary Commission, Capt.Anderson RE - Portable Unifilar, Dip-circle,Azimuth Compass, (loan of instruments used by the former Commission, under Major R.W.Haig RA)

Vienna, Central-Anstatalt fur Meteorologie & Erdmagnetismus, Prof. C.Jelinek - Set Kew Pattern Magnetographs*, Dip needles* x2 , alterations to four others for a Repsold Dip-circle

Anemometer, Robinson dial x4

Rain Gauge

1872/73

HMS *Challenger* - Dip needle x2

London, Casella, [instrument maker] - Dip-circles x3

Manila Observatory - Unifilar, Dip-circle

Oxford, Prof.Clifton - Unifilar

Rotterdam, Dr.E.van Rijckevorsel - Unifilar, Dip-circle

Anemometer, Robinson dial

Anemometer, by Oxley of Manchester (Failed).

Rain gauge

1873/74

Standard Thermometer x18

[?Batavia Observatory], Dr.E.van Rijckevorsel - Needles x2

Cambridge, Prof.J Clerk-Maxwell - Unifilar

HMS Challenger - Needle

Kasan [/Persia], Prof.Smirnov - Magnet, Needles x2

Lisbon Observatory, Don Luiz - Magnet

London, P.Adie [instrument maker]

London, Casella [instrument maker] - Dip Circle x2

London, Royal Geographical Society - Azimuth Compass x3

Manchester, Prof.B.Stewart, for use abroad - Unifilar, Dip-circle

St Petersburg, Prof.Wild - Dip Circle, Fox's Circle x2

Shanghai, Zi-ka Wie Observatory, Rev.A.M.Colombel SJ - Set of Magnetographs*

[Stoneyhurst College Observatory], Rev.S J Perry SJ - Unifilar

Toronto Observatory, Mr Kingston - Barograph,Thermograph

Utrecht, Prof.Buys Ballot - Magnet

Anemometer, Robinson dial x14

Rain Guage x13

1874/75

Standard Thermometer x13

Arctic Expedition - Unifilar x2, Declinometer x2, Barrow Dip-circle x2, Fox's circle x2

HMS *Challenger* - Dip Needle

[London] Admiralty - Magnets x3

London], Staff-Commander Creak RN – Fox's Circle

Mauritius Observatory - Thermograph

Moncalieri Observatory, Rev, F.Denza - Unifilar*, Dip Circle*

San Fernando Marine Observatory, Spain, Capt. C.Pujazon - Set of Magnetographs*

Anemometer, Robinson dial x6

Rain gauge x3

1875/76

Standard Thermometer x10

Batavia Observatory, Dr.Rijkevorsel - Dip-needles x2

Bombay, Colaba Observatory, Mr Chambers - Dip-needle

Coimbra, Dr. J.A. da Souza - Dip-circle*

[Horten] Norway, Lieut. C.Wille Norwegian Navy - Unifilar, Dip-circle, Fox's circle

Lisbon Observatory, Senhor Capello - Dip-needles x2

London, Elliot Bros [instrument makers] - Unifilar

London, Royal Naval College - Unifilar

Mauritius Observatory, Mr Meldrum - Dip-needles x2

St.Petersburg, Capt.Jelagin - Dip-circle

Shanghai, Zi-ka-Wei Observatory - Magnets x3, Dip-circle* with telescope for use as an altazimuth, Tabulating instrument*

Anemometer, Robinson dial x20

Rain gauge x29

1876/77

Standard Thermometer x12

Batavia Observatory, Dr.van der Stok - Set of Magnetographs supplied in 1860, re-verified after repair and alterations, Collimator magnet

Brussels Observatory, Prof.Houzaeu - Dip-circle*

Coimbra, Dr.Da Souza, - Unifilar*

Dorpat, Prof.Weihrauch - Dip-circle*

Kazan [?Persia], Prof.Smirnow - Dip-needles* x2

Potsdam Astrophysical Observatory, Dr Vogel - Set of Magnetographs*

Toronto Observatory, Mr Kingston - Collimator magnet*

Vice-Admiral Sir Charles Shadwell - Dip-circle with extra needles

Anemometer, Robinson dial x5

Rain gauge x11

1877/78

Standard Thermometer x14

Brussels Observatory - Set of Magnetographs, Barograph,Thermograph

Dutch Arctic Expedition - Unifilar, Dip-circle, Fox's-circle, Azimuth compass

Horten, Norway, Capt.C.Wille [Norwegian Navy] - Unifilar*, Dip-circle*, Fox's circle

Lisbon Observatory,Senor Capello - Dip-circle*

London, Negretti & Zambra [instrument makers] - Unifilar

St.Petersburg, Dr Wild - Dip needle x2

San Fernando Marine Observatory, Spain - Unifilar*, Dip-circle* -

Shanghai, Zi-ka-Wei Observatory - Barograph,Thermograph

[Tokyo], Japanese Government - Thermograph

[Vienna], Austro-Hungarian Government - Dip-circle

Anemometer

1878/79

Standard Thermometers x12 - includes 3 specially constructed for Dr Thorpe, Leeds

Brussels Observatory, Prof. Houzeau - Unifilar*

Budapest, Dr.Guido Schenzl - Dip-circle by J Dover

[Horten, Norway], Capt.Wille, Norwegian Navy - Bifilar*

Kasan [?Persia], Prof.Smirnow - Dip needles x2

Lisbon Observatory, Senhor Capello - Unifilar*

Naples, Royal Observatory - Special thermometers* x2

Princeton, Prof.Young - Unifilar*, Dip-circle*

Rome, Prof.Ferrari - Dip needles* x2

San Fernando Marine Observatory, Spain, Don C.Pujazon - Tabulator*

Shanghai, Zi-Ka-Wei Observatory - Thermograph tubes x2

Utrecht, Lt.van Hasselt - Dip-circle*

[Vienna], Austro-Hungarian Government - Dip-circle by Barrow & Co

Washington, Bureau of Navigation, Prof. Greene - Unifilar*, Dip-circle*, Fox's circle*, apparatus for determination of temperature and induction coefficients of Magnets*

Anemometer x2

Rain gauge x6

1879/80

Standard Thermometer x 17

Standard Thermometers special set - Bureau International des Poids et Mesurs, Paris

London, Casella - Dip-circle by Casella x4

London, Elliott Bros.[instrument makers] - Unifilar by Gibson, Dip needles x2

Russian Expedition to the mouth of the Lena - Dip-circle*

[Rotterdam], Dr.E. van Ricjkevorsel - Dip needles x3

St Petersburg, Dr Wild - Magnetograph needles*

Shanghai, Zi-ka-Wei Observatory, Rev.M.Decheverens SJ - Magnetograph needles x2

Tiflis [Georgia]Dr.Mielberg - Dip-circle*

Anemometer x12

1880/81

Standard Thermometer x10 - apparently excludes the exchange of a Standard Thermometer with Prof. Rowland of Johns Hopkins University USA, who gave Kew standard thermometer, Baudin 7835

Bombay, Colaba Observatory - Dip needle* x2

Copenhagen, Capt.Hoffmeyer - Dip-circle*

Liege, Prof.Perard - Unifilar*, Dip-circle*

Lisbon Observatory, Senhor Capello - Dip needle*

London, Casella [instrument maker] - Unifilar, Dip-circle x3

London, Elliott Bros.[instrument makers] - Dip needle x2

Nice Observatory - Set of self recording

Magnetographs
Rome, Prof. P.Tachini, [Gianicolio Observatory] - Unifilar*, Dip-circle*
Stockholm, Prof.Malmberg - Dip-circle*
Anemometer x3
Rain gauge x6

1881/82

Standard Thermometer x11
Adelaide,Australia, Government astronomer - Barograph,Thermograph
Coimbra, Dr.Viegas - Vertical force needle*
Hamburg, Deutsche Seewarte, Dr.Neumayer - Dip-circle* x2
Helsingfors, Prof.Nordenskiold - Dip-circle*
Lisbon, Senhor Capello - Agates for dip circle*
London, Casella [instrument maker, London] - Dip-circle
[London], Mr.Dowson
London, Elliot Bros.[instrument makers, London]- Unifilar x2, Dip-circle x2
[London],Meteorological Society, (for spire of Boston Church, Lincs.) - Siemens Electrical Thermometer
London, Negretti & Zambra [instrument makers] - Unifilar
Mauritius Observatory, (Crown Agents) - Standard barometer
Naples, Prof.Brioschi - Dip-circle*
[Rome], Italian Meteorological Service, Prof. P.Tachini - Standard Barometer
Rotterdam, Dr.Rijkevorsel - Deflection bar*, Magnetising bar* x2
St Petersburg, Dr Wild - Dip-circle*
Shanghai, Zi-Ka-Wei Observatory - Unifilar*
Toronto Observatory - Unifilar*
Utrecht, M.Snellen - Dip-circle*
Vienna, Dr.Hann - Dip-circle*
Anemometer x 12
Rain gauge x4

1882/83

Standard Thermometer x7
Bari, Insitut Technique et Nautique de Bari, Italy - Portable Thomson electrometer*
Charlton, Dover [instrument maker] - Dip-circle
Hong Kong Observatory - Barograph, Thermograph, Glass scales x5 (made at Kew)
Lisbon Observatory, Senhor Capello - Kew pattern electrograph*, Thomson quadrant electrometer*
London, Casella [instrument maker]Dip-circle x2
London, Elliott Brothers [instrument makers] - Unifilar x6
Lyons Observatory, l'Abbe Philippe - Set of Magnetometers*
Naples, Prof.Brioschi - Unifilar*
Rome, Rev.Prof. G.S.Ferrari SJ [Gianicolio Observatory] - Unifilar*
Shanghai, Zi-ka-Wei Observatory - Anemograph
[Tokyo], Japanese Hydrographic Department - Barograph
Toronto Observatory - Glass tabulating scales for magnetograph curves (made at Kew)
Uppsala, Prof.Thalen - Dip-circle*
Anemometer x12
Rain Gauge x9

1883/84

Standard Thermometer x 10
Greely Relief Expedition - Dip needles x2
Leeds College of Science, Prof.Rucker - Unifilar*, Robinson pattern Dip-circle*
Lisbon Observatory, Senhor Capello - Robinson pattern Dip-circle*
London, Negretti & Zambra [instrument makers] - Unifilar, Dip-circle
London, Elliott Bros.[instrument makers] - Unifilar x3, Dip-circle x3 London
Rome, Prof.Tacchini - Collimating magnet*x6
St Petersburg, Dr Wild - Dip-circle*
[Tokyo], Japanese Government - Thermograph
[Washington], United States Government - Fox's circle, with gimbal tables* x2, Set self recording magnetometers*
Anemometer x2
Rain gauge x3
Richard Temperature recorder
Richard Humidity recorder

1884/85

Standard Thermometer x3
Charlton, Dover [instrument maker] - Inclinometer,
London,Admiralty - Unifilar, Collimating Magnets x2, Inclinometer
London, Elliott Bros.[instrument makers] - Unifilar x2, Inclinometer
Mauritius Observatory - Inclinometer needle* x6
[St Petersburg] Dr Wild - Inclinometer needle* x6
Washington, Bureau of Navigation - Fox's circle
Anemometer x15 - includes 1x electrical anemometer
Evaporation gauge
Gauge Barometer, for comparing aneroids x2
Rain gauge x20
Richard Thermograph
Sunshine Recorder
Thermograph Thermometers x 4

1885/86

Standard Thermometer x7
Ekaterinburg Observatory - Inclinometer*
Falmouth Observatory - Unifilar, Inclinometer
Helsingfors, Lighthouse Board - Inclinometer*
Lisbon Observatory - Dip needle* x2
Mauritius Observatory - Dip needle* x2
[Tokyo], Imperial Japanese Navy - Thomson's patent compass* x7, Vertical Force instrument* x7
Valencia - Anemograph (electrical)
Washington, Bureau of Navigation - Inclinometer* x2
Anemometer x15
Barograph, Redier type
Hygrometer, Richard type
Inclinometer x2
Rain Gauge x6
Unifilar

1886/87

Standard Thermometer x5
Coimbra Observatory, Dr A.S.Viegas - Beckley pattern Anemograph,
Formosa, Imperial Chinese Customs - Beckley pattern Anemograph
Hong Kong Observatory, Dr Doberck - Alluard Hygrometer*, Crova Hygrometer*, Dines Hygrometer*
Lisbon Observatory - Inclinometer needle* x2, Magnet for declination*
London, Meteorological Council - Aneroid with Bourdon tube, by Richard Freres, Paris x2, Beckley Anemograph x2
Mauritius Observatory - Inclinometer*, Beckley pattern Rain gauge with Stoneyhurst discharger
Rome, Prof. F.Brioschi - Collimating magnet*
Tokio University, Japan - Inclinometer*
Turin University, Prof. Naccori - Inclinometer*, Collimating magnet x2*
Anemometer x3
Inclinometer x3
Magnet x6
Rain Gauge x7
Sunshine recorder x2
Unifilar x4

1887/88

Standard Thermometer x 7
Colaba Observatory, Bombay - Inclinometer needle* x2
Tiflis Observatory, [?Georgia] - Inclinometer*
Utrecht Observatory - Inclinometer needle *x2
Washington, United States Navy Department - Inclinometer needle* x2
Anemometer x2
Inclinometer
Magnet x3
Rain Gauge x3
Sunshine recorder x3
Unifilar

1888/89

Standard Thermometers x6
Charlottenburg, Sweden, Dr Lowenherz -

Low range aneroid barometer*
Coimbra Observatory - Jordan type sunshine recorder*
Mauritius Observatory -Magnet* x3
Modena University, Italy - Inclinometer*
St Petersburg Observatory - Jordan type sunshine recorder*
St Petersburg, Dr H.Wild - Ammeter*, Voltmeter*
Washington, United States Navy Department - Unifilar*, Inclinometer*
Anemometer x3
Inclinometer x4
Rain Gauge x15
Sunshine recorder x2
Unifilar x4

1889/90

Standard Thermometer x3
Hong Kong Observatory - Dip needle x2
Italy, Prof. Chistoni - Collimator magnet* x2
Lisbon Observatory, Senhor Capello - Dip needle* x2
London, War Office, for Netley Hospital - Barometer
Rome, Rev F.Denza [Specola Vaticana] - Inclinometer*
Anemometer x14
Inclinometer
Magnet x2
Rain Gauge x15
Rain measure x33
Sunshine recorder x3
Unifilar x3

1890/91

Standard Thermometer x4
Brazil, Meteorological Department - Unifilar*, Inclinometer*
London, Richmond Terrace Gardens Committee - Richard aneroid*, set of thermometers*
London, Royal Observatory Greenwich - Unifilar*
Mauritius Observatory - Magnetograph needle* x2, Electrical anemometer*
Rome, Vatican Observatory - Unifilar*
The Hague - Inclinometer (after repair), Magnetograph needle* x2, Magnet* x2
Anemometer x19
Inclinometer x3
Magnet x2
Rain gauge x17
Rain measure x 39
Sunshine recorder
Unifilar 3

1892

Standard Thermometer x3
Austro-Hungarian Embassy, London - Dip needle* x2
Copenhagen, Meteorological Institute - Dip needle* x2
Hong Kong Observatory - Set of 24 Thermometers*
Mauritius, Royal Alfred Observatory - Dip needle*, Clifton electrometer*, Water dropping collector*, Battery of 60 chloride of silver cells*
Anemometer x4
Deflector x 20
Inclinometer
Magnet
Rain gauge x9
Rain measure x 13
Sunshine recorder
Unifilar
Vertical force instrument x5

1893

Standard Thermometer x 3
Anemometer x24
Deflector x 4
Inclinometer x2
Magnet x3
Rain gauge x19
Rain measure x 37
Sunshine recorder
Unifilar

1894

Standard Thermometer x3
Anemometer x2
Deflector x 1
Inclinometer x3
Magnet x14
Rain gauge x6
Rain measure x 10
Sunshine recorder
Unifilar x7
Vertical force instrument x 6

1895

Standard Thermometer x2
Anemometer x7
Deflector x20
Inclinometer x 4
Magnet x2
Rain gauge x9
Rain measuring glass x90
Unifilar x4
Vertical force instrument x3

1896

Standard Thermometer x5
Anemometer x12
Inclinometer x 8
Magnet x4
Rain gauge x17
Rain measuring glass x26
Sunshine recorder x2
Unifilar x3

1897

Colaba Observatory, Bombay - Drum chronograph* for astronomical work, by T.Cooke & Sons, York
Melbourne Observatory, Mr P.Baracchi, Acting government astronomer, for use in Australia, New Zealand or the Borchgrevink Antarctic Expedition - Unifilar and dip-circle, formerly used on the Jackson-Harmsworth Polar Expedition (Loaned)
St Petersburg - Cambell-Stokes sunshine recorder* (a number)
Anemometer x3
Declinomter x3
Deflector x4
Inclinometer x5
Magnet x2
Rain gauge x 27
Rain measuring glass x31
Sunshine recorder x10
Unifilar x 4
Vertical force instrument x 4

1898

Standard Thermometer x2
Anemometer x11
Deflector x3
Inclinometer x5
Magnet x2
Rain gauge x 12
Rain measuring glass x10
Unifilar x6

1899

Standard Thermometer x2
Mauritius Observatory - Dip needle* x2, Standard barometer*, Maximum & minimum thermometer*, Ozone cage*, Astronomical globe*
St.Petersburg - Dip-circle*, Dip needle* x4 , Pocket aneroid*, Kew pattern self-recording Robinson anemometer*
Toronto - Dip-circle*, Dip needle* x2
Uppsala - Dip needle* x4
Anemometer x23
Deflector x6
Inclinometer x9
Magnet x3
Rain gauge x19
Rain measuring glass x 44
Sunshine recorder x6
Vertical force instrument

Author's address:
11 Pensham Hill
Pershore WR10 3HA, England
djbryden@fish.co.uk