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ROYAL SOCIETY.

[Continued from p. 151.]

March 15, 1877.—Dr. J. Dalton Hooker, C.B., President, in the Chair.

THE following paper was read:—

"Description of the Process of verifying Thermometers at the Kew Observatory." By Francis Galton, F.R.S.

It may be of interest to describe the method recently adopted at the Kew Observatory of verifying thermometers by comparison at different temperatures with a standard instrument, since a large proportion of the various thermometrical determinations made by

English physicists are dependent for their accuracy upon that of the verifications at Kew. Many thousands of thermometers have already been verified by the apparatus about to be described.

Up to the year 1875 the apparatus for this purpose at the Kew Observatory was of the rudest character.

It was simply a glass jar $9\frac{1}{2}$ inches wide and 18 inches deep, filled with hot water and standing on a turntable, in which a brass frame was placed.

The thermometers were attached to this framework, and the observer having well agitated the water with a plunger, read the instruments in succession through the glass as he turned the jar round before him, reading each thermometer as it passed. He first turned it round from right to left, and then back again from left to right. Each thermometer was thus read twice, and the mean of the pair of readings was taken. It is obvious that if the rate of cooling of the water be uniform, and if the thermometers are observed at precisely equal intervals, the mean of every pair of observations would be strictly referable to the temperature of the water at the same moment of time, namely to that which is half-way between the beginning and end of the entire set. It is needless to point out that these conditions can never be strictly fulfilled, although, notwithstanding the imperfection of the process and the coarseness of the apparatus, the observers acquired much certainty and skill in its manipulation. Still the time occupied was unnecessarily great, and the chance of error, owing to variations in the rate of cooling of the water, was larger than it need be. Partly owing to this latter reason, and partly to the fact that the number of thermometers sent to be tested has considerably increased (being now not less than 3000 annually), I thought it advisable to design and propose to my colleagues of the Kew Committee the construction of an instrument of a much more substantial and adequate character; and to this the Committee assented. I was subsequently indebted for many suggestions to Mr. De La Rue, and also to Mr. R. Munro, of 24 Clerkenwell Green, London, by whom it was finally made. It has now been at work for two years, and its performance is quite satisfactory; experience has in the mean time suggested a few emendations and simplifications, and I will therefore describe the instrument as at present in use.

The apparatus (see figs. 1 & 2) consists essentially of four parts:—

(1) A water-vessel.
(2) An agitator, worked by a handle on the outside.
(3) An external heating arrangement.
(4) A frame on which to hang the thermometers, turned by a handle on the outside.

(1) *The Water-vessel.*

This is a cylinder of stout copper, 2 ft. 2 in. high and 1 ft. in diameter. In its base there is a central aperture through which the concentric vertical axes are passed, which respectively carry the agitator and the thermometer frame; the top of the cylinder is entirely open; a vertical slit, 1 ft. 10 in. long and $4\frac{1}{2}$ in. wide, is cut in the side of the cylinder and the slit is glazed with a stout sheet of plate-glass, the joints being made water- and steam-tight by means of india-rubber packing.

The cylinder is placed inside a wooden box, taller than itself, and 1 ft. 5 in. square at its base, the space between it and the sides of the box being filled with sawdust, whilst the exterior of the box is completely covered with kamptulicon, in order to retain the heat of the water in the enclosed vessel as much as possible. An aperture somewhat larger than that in the cylinder is cut in the side of the box in front of it, and is also glazed with plate-glass.

A lid, containing 3 inches of sawdust, covered with a sheet of kamptulicon, can be shut tightly down on the top of the cylinder and box, the escape of the vapour given off during heating being provided for by means of a steam-pipe.

Pipes lead from the top and bottom of the water-vessel to an exterior pipe ending in a funnel above and a cock below, so that water may be poured in or drawn off from the vessel as desired.

The whole is firmly fixed to a stout wooden stand about 2 ft. high.

(2) *The Agitator* (see fig. 2).

A stout and hollow brass axis, $2\frac{1}{4}$ in. in diameter, passes vertically up through the centre of the base of the water-vessel, carrying three sets of helical vanes, one above the other, arranged so that the upper and lower vanes form segments of right-handed screws, whilst the intermediate vanes are left-handed. The inclination of every vane is adjustable.

The lower end of the axis passes through a stuffing-box in the bottom of the cylinder, and is connected by gearing to a crank-handle projecting outside the apparatus. It can be turned easily by the hand of the observer, who thereby is able to agitate the water throughout the whole depth of the vessel.

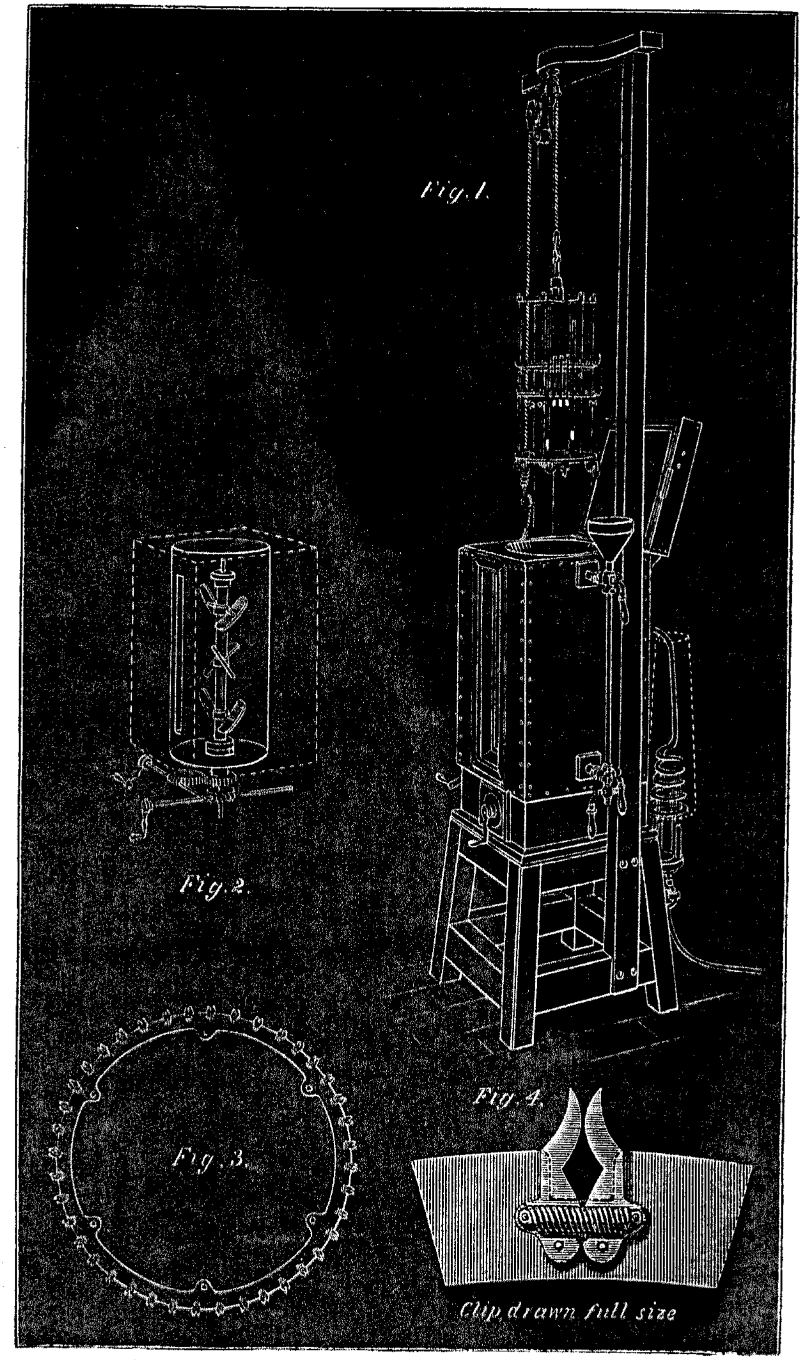
(3) *The Heating-Apparatus* (see fig. 1).

This is a copper tube 0·6 in. in diameter, which, issuing from the back of the water-vessel near the bottom, is carried through the wooden casing of the instrument, and is then coiled into a vertical spiral of six turns, gradually diminishing in diameter. The end of the tube is afterwards brought back into the water-vessel.

A cluster of Bunsen burners being placed beneath the coil serves to heat it and to make the water circulate inside the cylinder, thus warming the whole of its contents.

Experiment shows that, with the small coil used, 10 gallons of cold water can be boiled in about six hours from the time of lighting the gas; in practice, however, when it is required to test thermometers near the boiling-point only (mountain thermometers, for example) the apparatus is filled with boiling water out of kettles put on an ordinary fire.

A cone of sheet-copper is usually placed round the coil as a jacket, in order to retain the heat from the gas-burners as much as



possible; this is shown by dotted lines in the drawing. A cock at the lower end of the coil permits of the stoppage of the circulation of the water through the pipe.

(4) *The Thermometer Frame.*

The thermometers to be compared are hung side by side round the circumference of two brass rings, 10¾ in. in diameter, that are attached to the side rods of a cylindrical frame. The thermometers are held in their places against the ring by spring clips, one of which is shown full size in fig. 4, and one of the rings is shown in fig. 3; the latter slide up and down the brass rods that form the sides of the cylindrical framework, and are clamped at such a distance apart as may best suit the thermometer under examination.

Forty thermometers can be suspended at a time. The bottom of the frame is provided with six rollers—three placed radially, for the purpose of guiding it up and down the interior of the water-vessel; and three tangentially and projecting below the base, in order to support the frame whilst putting on or taking off the thermometers. This operation is performed when the frame is standing on the closed lid of the box, a circular brass ring being screwed to the lid to prevent the frame running off when being turned round by the operator.

The top of the frame consists of spokes radiating from a hollow socket that drops over the end of an upright steel rod, which, passing through the axis of the agitator, projects above it (see fig. 2). A plug is then screwed into the top of this rod and clamps the frame, which is supported by it; the frame, with the thermometers, can then be rotated in the water by turning this rod. This turning is effected from the outside through a wheel fixed to its projecting lower extremity, into which an endless screw, driven by a crank in front of the apparatus, is geared. The observer, facing the glazed slit, can bring the thermometers hung round the frame before him one by one as quickly as he likes.

For the convenience of moving the thermometer frame into and out of the water-vessel, a cord is carried over the apparatus round pulleys, as seen in fig. 1, so that the attendant can hook its end to the ring at the top of the frame, and twist or lower it with the grestest facility.

The general character of the process of comparison is to turn down the gas and to close circulation in the pipe by turning the stopcock; the water is then agitated, and is afterwards left at rest until the set is finished. The thermometer frame is turned once round forwards and once backwards in each process of comparison, each instrument being read off twice, the mean of the two being the result aimed at.

Mr. Whipple, the Superintendent of the Observatory, has made at my request a large number of experiments on the variations of temperature under different conditions, and on other matters relating to the working of the apparatus. It will be sufficient if I give a few summary tables of the results.

The mean variation of temperature during a double process of comparing each of twenty sets of thermometers, each set averaging nineteen instruments, and each instrument being read four times, was as follows:—

Temperature at which the comparison was made.	50°	70°	80°	90°	100°	110°
Mean variation during each set	+0·06	±0·07	±0·06	±0·07	±0·09	±0·15

The extreme variation of 0°·30 occurred in one case, and that of 0°·25 in three cases.

It takes about four minutes to read a complete set of ordinary thermometers.

The rate of heating by gas, and of cooling after the gas has been wholly turned off, is of course much affected by the temperature of the air of the room; it may be roughly taken as follows:—

When the water in the vessel is about ...	45°	100°	150°	200°
Rise of temperature in 5 minutes when the gas is turned fully on	2°·80	2°·26	1°·95	1°·45
Fall of temperature in 5 minutes when the gas is turned wholly off...........	......	0°·25	0°·60	1°·00

The rate of cooling is much reduced when the process consists in first raising the water to the highest required temperature, and then cooling it by successive additions of cold water. The heat of the stuffing that surrounds the vessel being thus much higher than the water it contains, keeps it at an equable temperature.

The temperature of the water in the vessel, after agitating it and allowing it to settle, differs somewhat at different levels; this is due to the impossibility of securing perfect intermixture and to the variations of the temperature of the stuffing in respect to that of the water. The greatest differences observed between a thermometer whose bulb was immersed 2 inches below the level of the water and one that was immersed 19 inches was 0°·68.