

whether any coincidence of period or epoch is traceable. Now the facts of the solar spots, as they have been recently made known to us by the assiduous and systematic labours of Schwabe, present us with phenomena which appear to indicate the existence of some periodical affection of an outer envelope, or photosphere, of the sun; and it is certainly a most striking coincidence that the period, and the epochs of maxima and minima, which M. Schwabe has assigned to the variation of the solar spots, are absolutely identical with those which have been here assigned to the magnetic variations." From the results of his observations of the solar spots from the years 1826 to 1850, M. Schwabe has derived the conclusion that "the numbers in the table leave no room to doubt that, at least from the years 1826 to 1850, the solar spots have shown a period of about ten years, with maxima in 1828, 1837, and 1848, and minima in 1833 and 1843." M. Schwabe has not been able to derive from the indications of the thermometer or barometer any sensible connection between climatic conditions and the number of spots. The same remark would of course hold good in respect to the connection of climatic conditions with the magnetic inequalities, as their periodical variation corresponds with that of the solar spots. But it is quite conceivable that affections of the gaseous envelope of the sun, or the causes occasioning those affections, may give rise to sensible magnetical effects at the surface of our planet, without producing sensible thermic effects.

May 13, 1852.

WILLIAM SPENCE, Esq., V.P., in the Chair.

The following communications were read:—

1. "Report of the general process adopted in Graduating and Comparing the Standard Meteorological Instruments for the Kew Observatory." By Mr. John Welsh. Communicated by Col. Sabine on the part of the Committee of Recommendations of the Government Grant. Received May 6, 1852.

In offering to the Committee a short statement of the progress made at the Kew Observatory in the construction and verification of thermometers, I shall first describe generally the method pursued in the graduation of standard instruments.

The plan of operations hitherto adopted has been that proposed by M. Regnault, and consists essentially of the following steps:—1st. Calibration of the tube: 2nd. Graduation of the scale: and 3rd. The determination of the scale coefficients.

1. *Calibration*.—A tube having been selected as being tolerably free from all visible defects, a short column of mercury, generally less than one inch in length, is introduced. The tube is then attached to the frame of Perreaux's dividing-engine, and by means of flexible tubing is put in connection at both ends with india-rubber bags, the pressure upon which can be regulated by means of screws. The

mercury is then brought to the part of the tube where the graduation is proposed to commence. The cutting-frame of the engine carries also a small microscope with cross wires in its focus; on turning the dividing-screw, the microscope-wire is brought to coincide with the first end of the mercury, and the screw is then turned forward until the wire reaches the second end; the length of the column is thus given in revolutions of the screw. By means of the india-rubber bags, the mercury is made to move along the tube until the first end coincides again with the microscope-wire; the length of the column is again measured, and the mercury again moved forward; the same process being repeated until the column has been measured for each length of itself through the whole extent of the proposed scale. Permanent marks are made on the glass at the points of commencement and ending of the calibration. If the progress of the numbers shows any considerable irregularity in the tube, and as a verification of the first set of measures, it is well to repeat the calibration, commencing in this case at a point one-half the length of the column in advance of the original starting-point. A series of measures interpolated from the two sets may then be adopted. Some experience is necessary in order to bring with facility the end of the mercury exactly to the wire of the microscope; but when care is taken to use very pure mercury and clean tubes, the operation can generally, after a little trouble, be accomplished with much accuracy. M. Regnault, I believe, recommends that the motion of the mercury should be regulated by the breath, a drying substance being interposed to prevent moisture entering the tube. This method was employed for some of the first instruments made at Kew, but was abandoned in favour of the elastic bags.

2. *Graduation.*—The measured lengths of the column of mercury in its successive steps along the tube correspond to equal volumes. Assuming that the calibre of the tube does not vary throughout the small length of the calibrating column, if we divide the spaces occupied successively by the mercury into an equal number of parts, it is evident that the divisions will represent the same *capacity*, although they may be of very different *lengths*. Before making the tube into a thermometer, the divisions of the scale may be verified by introducing a longer column of mercury, and examining whether the column occupies an equal number of divisions in different parts of the scale. If there should be any irregularity, a table of corrections may readily be formed. It will generally be found, however, that if the operations have been performed with care, and the tube is not very faulty, no correction will be necessary. The divisions are cut with a fine needle-point upon a coating of engravers' varnish, and afterwards etched with fluoric acid. The required dimensions of the bulb may be found approximately by weighing a measured length of the mercurial column, and from the known expansion of mercury and its specific gravity computing the capacity of the bulb.

3. *Determination of the scale coefficient.*—The thermometer having been filled with mercury, we have an instrument the divisions of whose scale represent equal increments of the volume of the fluid,

but are entirely of an arbitrary value. If now we determine the points of the scale at which the mercury stands in freezing and boiling water, we can immediately convert the arbitrary scale-readings into degrees of the ordinary scales of temperature. If a be the scale-reading for the freezing-point, and b that for the boiling-point, the temperature by Fahrenheit's scale corresponding to any reading

$$n = \left(\frac{n-a}{b-a} \right) 180 + 32.$$

The freezing-point is determined by placing

the thermometer in finely-pounded ice, from which the water is drained off as it melts. The boiling-point is ascertained by the form of apparatus employed by M. Regnault; the temperature observed is that of steam, whose elasticity is the same as that of the atmosphere. A small siphon water-gauge communicating with the interior of the vessel gives notice to the observer when the ebullition is being carried on too rapidly. The steam is generated from distilled water. The height of the barometer is observed at the time of the experiment, and the correction to a uniform height of 30 inches (reduced to 32°) is found from Regnault's table. In determining the fixed points, the stems of the thermometers are kept vertical; if the subsequent comparisons with other instruments are made in the same position, no error will arise from the expansion of the bulb caused by the pressure of the column of mercury. If, however, the thermometers are intended to be used in any other than a vertical position, it becomes necessary to determine the fixed points also in a horizontal position.

In accordance with the plan here sketched, fifteen thermometers have been completed with arbitrary scales. About thirty more tubes have been calibrated, and the bulbs attached and filled, but the scales not yet divided. The principal object in graduating the tube with an arbitrary scale is the convenience it affords of testing the divisions before it is converted into a thermometer. It is now proposed to divide the scale at once into Fahrenheit degrees after the thermometer has been made, and to test the accuracy of the divisions afterwards by detaching a portion of the mercurial column and making it move along the tube. If the scale should not then be found correct, a table of its errors can be formed and furnished with the instrument, or the thermometer rejected. The scales of these thirty thermometers have not yet been proceeded with, as it is desirable, before doing so, to allow the freezing-point to have attained a permanent position. A few divisions have been cut on the tubes near the freezing-point, and the reading with reference to this short arbitrary scale taken from time to time in melting ice. The period elapsed since the construction of the thermometers has been too short to afford as yet much information as to the probable constancy of the freezing-points. They have, however, already shown generally a tendency to rise, in some cases to the extent of nearly 0°·3 Fahr., but in most of them it does not yet exceed 0°·1 or 0°·2. Another peculiarity in connection with the freezing-point has shown itself in almost all the thermometers yet tried. After a thermometer has been exposed for some weeks to the ordinary tem-

perature of the air, if its freezing-point be ascertained, and it be then suddenly exposed for a short time to the temperature of boiling water, and again immediately placed in ice, it is found that the latter determination of the freezing-point will be *lower* than the former by a very appreciable amount, generally between $0^{\circ}1$ and $0^{\circ}2$ Fahr. The freezing-point does not recover its previous position for some time, probably two or three weeks. This peculiar displacement of the freezing-point has been found to take place also in the case of a standard by Troughton and Simms belonging to the Royal Society. The freezing-point of this instrument, before being raised to the temperature of boiling water, was 32.25 , afterwards it had fallen to 32.15 . This displacement of the freezing-point has been remarked by Mr. Sheepshanks in the course of his experiments on standard thermometers*. From the experiments now in progress, it is to be hoped that, after a time, some approximation may be made to the laws of these perplexing phenomena.

The apparatus employed for comparing the indications of different thermometers, consists of a cylindrical glass vase 15 inches deep and $8\frac{1}{2}$ inches in diameter,—a stand for supporting the thermometers under comparison, and a means of agitating the water in such a way as completely to assimilate the temperature throughout the vessel. The stand for the thermometer is a vertical rod, supported by a small tripod resting on the bottom of the vase. The thermometers are suspended from hooks sliding on this rod, and adjustable to any height; they are arranged, with their bulbs at the same height in a circle 3 inches diameter round the rod, and kept fixed with sufficient firmness below by being strapped with elastic bands against a projecting six-rayed frame attached to the supporting rod. Six thermometers of almost any form and length can thus be compared at once. The agitator is a flat ring of tinned iron, about 2 inches broad, fitting easily within the vase, and connected by four light rods with a similar ring at top, which serves as a handle. A packing of india-rubber is placed on the outer rim of the plunger to prevent jarring against the glass. The flat tin ring is cut half across at several places, and the corners bent in various ways, so that when moved upwards and downwards the water is driven in *all* directions. The dimensions of the agitator are so arranged, that no part of it can possibly touch the thermometers when in operation. The vase, containing water, the stand with thermometers, and the agitator, are mounted upon a wooden revolving stand. The depth of water in the vase is always sufficient to include the whole of the column of mercury, the scales being observed through the water. In taking the observations, the observer, after agitating the water briskly for some time, turns the revolving stand till each thermometer is brought successively opposite to his eye, reading off the scales as quickly as possible to an assistant, who writes down the numbers. Proceeding in this way, I find that six thermometers can be read off and recorded easily in 20 seconds. It is of course desirable to make more than

* This fact, I find, is also mentioned in Faraday's "Chemical Manipulation," edit. 1827, p. 139.

one set of readings for each temperature; and in order to avoid as much as possible the changes which may occur during the reading off, it is well to reverse the order of observing the instruments, that is, to read them alternately in the order one to six, and six to one.

The following table contains the results of comparisons of six thermometers, and will show the accuracy which may be obtained by the method of comparison just described; it will also exhibit the accordance in the indications of instruments graduated according to Regnault's process. Each result is the mean of six comparisons. No optical assistance was used in reading off the scales. The freezing-points of all the instruments were determined on the same day, after the comparisons were made.

Results of Comparisons of various Thermometers, March 19, 1852.

Standard Thermometers.						Barrow, E.I.C., S 7, No. 4.	Newman (Makerstoun).		Troughton and Simms (Royal Society).					
Kew No. 4.		Kew No. 14.		Fastré 231 (Regnault).			Tempe- rature from mean of stand- ards.	Ob- served tempe- rature.	Diff. from mean of stand- ards.	Ob- served tempe- rature.	Diff. from mean of stand- ards.	Ob- served tempe- rature.	Diff. from mean of stand- ards.	
Ob- served tempe- rature.	Diff. from mean of stand- ards.	Ob- served tempe- rature.	Diff. from mean of stand- ards.	Ob- served tempe- rature.	Diff. from mean of stand- ards.									
°	°	°	°	°	°	32°00	32°05	+0°05	32°05	+0°05	32°25	+0°25		
38·69	−0·02	38·73	+0·02	38·72	+0·01	38·71	38·91	+0·20	38·86	+0·15	38·96	+0·25		
45°05	+0·01	45°03	−0·01	45°03	−0·01	45°04	45°30	+0·26	45°18	+0·14	45°30	+0·26		
49·96	0·00	49·97	+0·01	49·96	0·00	49·96	50°34	+0·38	50°23	+0·27	50°23	+0·27		
55·33	−0·02	55·35	0·00	55·37	+0·02	55·35	55°87	+0·52	55°75	+0·40	55°62	+0·27		
60°07	+0·01	60°06	0·00	60°05	−0·01	60°06	60°65	+0·59	60°58	+0·52	60°34	+0·28		
65·39	−0·01	65·39	−0·01	65°41	+0·01	65°40	65°99	+0·59	66°03	+0·63	65°65	+0·25		
69·93	0·00	69·92	−0·01	69·95	+0·02	69·93	70°57	+0·64	70°67	+0·74	70°22	+0·29		
74·69	0·00	74·68	−0·01	74·69	0·00	74·69	75·39	+0·70	75·54	+0·85	75°02	+0·33		
80°08	+0·02	80°03	−0·03	80°06	0·00	80°06	80°78	+0·72	81°00	+0·94	80°44	+0·38		
85·30	−0·01	85·30	−0·01	85·33	+0·02	85·31	86°10	+0·79	86°25	+0·94	85°75	+0·44		
90°50	0·00	90°49	−0·01	90°51	+0·01	90°50	91°36	+0·86	91°47	+0·97	90°87	+0·37		
95·29	+0·04	95·23	−0·02	95°24	−0·01	95°25	96°15	+0·90	96°32	+1·07	95°72	+0·47		
101·78	+0·01	101·76	−0·01	101·77	0·00	101·77	102°71	+0·94	103°04	+1·27	102°26	+0·49		
109·21	+0·05	109·11	−0·05	109·15	−0·01	109·16	110°08	+0·92	110°62	+1·46	109°58	+0·42		
						212·00							212·47	+0·47

The thermometers "Kew No. 4" and "Kew No. 14," were graduated on the stems by myself with arbitrary scales: the bulb of No. 4 is spherical, and is about $\frac{3}{4}$ inch diameter; that of No. 14 is cylindrical, $\frac{3}{4}$ -inch long and $\frac{1}{4}$ inch diameter, and very sensitive. "Fastré No. 231 (Regnault)" is a standard by Fastré of Paris, also graduated on the stem with an arbitrary scale according to Regnault's process. This instrument was examined and approved by M. Regnault; the determination by him of the scale coefficient agreed closely with that afterwards made at Kew. The bulb is cylindrical, about $1\frac{1}{2}$ inch long and $\frac{1}{4}$ inch diameter. "Barrow, F.I.C., S 7, No. 4," is one of a number of thermometers made for the East India Company and sent to Kew for examination. Its scale

is of brass divided to degrees. "Newman (Makerstoun)" is the instrument which was supplied to the Makerstoun Observatory as a standard, and to whose indications the results of the temperature observations made there since 1841 have been "corrected." It was, at my suggestion, sent to Kew by Sir Thomas Brisbane for comparison with our standards. "Troughton and Simms (Royal Society)" is a standard belonging to the Royal Society. As its scale extends to above 212, its boiling-point was examined in the same apparatus employed for the Kew standards, its brass scale remaining attached to the tube. It was found to read $212^{\circ}\cdot7$ when the barometer, reduced to 32° , stood at $30\cdot136$ inches.

The errors of a thermometer which has been already carefully examined between 32° and about 100° , may be obtained with considerable accuracy for temperatures below 32° , without using a freezing mixture, by the following process. Detach from the column of mercury a portion which will occupy about 40 or 50 degrees of the scale: bring this column within the known part of the scale. Let a, b be the readings at the upper and lower ends respectively; α, β the index errors at these points as determined by comparison with a standard. Move the column until its lower end coincides with some degree below 32° , the upper end being within the compared portion of the scale. Let c, d be the scale-readings for the upper and lower ends in the new position, γ being the scale error corresponding to c . The error of the scale at d will then be

$$d - \{c - \gamma - (a - \alpha - b - \beta)\}.$$

The true length of the detached column may be obtained with increased accuracy by taking a mean of several measures within the known part of the scale. This method was adopted for "Newman (Makerstoun)" and "Troughton and Simms (Royal Society)," and the following errors obtained:—

Newman (Makerstoun).		Troughton and Simms (R.S.).	
Temperature.	Error.	Temperature.	Error.
$0^{\circ}\cdot7$	$-0^{\circ}\cdot05$	$5^{\circ}\cdot1$	$+0^{\circ}\cdot14$
$6^{\circ}\cdot2$	$-0^{\circ}\cdot08$	$10^{\circ}\cdot0$	$+0^{\circ}\cdot17$
$10^{\circ}\cdot7$	$-0^{\circ}\cdot12$	$15^{\circ}\cdot0$	$+0^{\circ}\cdot16$
$14^{\circ}\cdot6$	$-0^{\circ}\cdot10$	$20^{\circ}\cdot0$	$+0^{\circ}\cdot16$
$20^{\circ}\cdot2$	$-0^{\circ}\cdot04$	$24^{\circ}\cdot8$	$+0^{\circ}\cdot16$
$25^{\circ}\cdot8$	$0^{\circ}\cdot00$		

The error of "Newman" had been previously found, by comparing with a standard in a freezing mixture at -3° , to be inappreciable.

Mr. Welsh's Report, No. 2.

"On the Graduation of the Thermometers supplied from the Kew Observatory for the use of the Arctic Searching Expedition under Sir Edward Belcher."

These instruments were twelve in number, seven mercurial and five spirit thermometers, graduated for low temperatures. The pro-