

would direct attention to the new form of air-trap in the cistern, and to the drying tube in the short leg; the latter would prevent moisture from entering the cistern, and the former the air from ascending into the long leg. If any inconvenience should be felt by the short branch assuming in time a dirty appearance, the dirt could be removed with the cleaning rod, or a piece of pencil covered with a strip of tissue paper, linen, &c., swinging the instrument into an inclined position, and removing the disc. Air-traps with contracted openings were prejudicial to the sensitiveness of barometers, but this objection did not apply to his instrument. The fact of having avoided the contracted air-trap and the capillary ends, retaining nevertheless all the advantages they otherwise possessed, showed that the cistern-siphon had some practical value. The idea of constructing a siphon barometer which could be taken to pieces so as to clean the glass and refill it, was, he imagined, a happy one, and he thought if observers made themselves familiar with the instrument they would adopt it, not only as a travelling barometer, but also as a stationary standard. The drying tube afforded the only means of preserving barometers for years in sound condition, for it was through the moisture inside the glass tube that the air adhered to the glass, and which might in time creep up to the vacuum; besides, pure mercury when dry never became tarnished. The back pressure, owing to mercurial vapour in the Torricellian vacuum, was insignificant, but as its existence was undeniable it ought to be taken into consideration. A very pertinent remark had been made expressing some doubt as to the perfect equality of the diameter of the tube of both legs. To this he would say that the short leg was cut off from the top of the long tube before it was sealed, and could not well differ from it in a well-formed tube, but the two legs could be tested by pouring small quantities of mercury into the short branch by the opening of the drying tube, and the heights compared, and if unequal, the tube be rejected.

VIII. *On the Relation existing between the Duration of Sunshine, the Amount of Solar Radiation, and the Temperature indicated by the Black-bulb Thermometer in vacuo.* By G. M. WHIPPLE, B.Sc., F.R.A.S., F.M.S., Superintendent of the Kew Observatory. (Plate XXV.)

[Received January 8th—Read February 19th, 1870.]

THE subject of solar radiation, as measured by readings of a blackened bulb thermometer *in vacuo*, has already been discussed with considerable fulness in papers read before the Meteorological Society by Mr. Park Harrison, the Rev. Fonwick Stow, and Mr. Nash; but although Mr. Harrison, in his paper, printed in the Quarterly Journal of the Society, Vol. II. p. 455, has considered solar radiation in its relation to cloud and vapour, I do not find that the question has been examined in the light in which I have now, by the kind permission of the Kew Committee, the honour of placing it before the Society.

The investigation could only be carried out by the aid of the sunshine recorder, for which meteorologists are mainly indebted to Mr. Campbell and Mr. Scott. The observations were made in 1877 at the Kew Observatory, the values for the daily duration of sunshine being those already discussed as to their relation to the similar results obtained at the Royal Observatory, Greenwich, in the Quarterly Journal, Vol. IV. p. 201.

The Rev. F. Stow has shown, in his exhaustive paper on the Black-bulb thermometer, in the Quarterly Journal, Vol. I. p. 188, that great variability

still obtains among the readings of this class of instruments; and although much ingenuity has been bestowed upon it by opticians in the endeavour to reduce to the utmost the causes which tend to bring about the observed discrepancies, their efforts have not as yet been crowned with entire success.

At the Kew Observatory, in order to reduce the instrumental error of this class of observation to a minimum, four thermometers are employed—two of Negretti and Zambra's patent, and two of Hicks's patent, as nearly as possible of the same dimensions, and compared rigorously with ordinary standard thermometers. These instruments are read and set daily at 10 a.m., and being fixed side by side on a frame-work with the bulbs 4 feet above the grass, freely exposed on all sides, their mean may be assumed to be a tolerably correct value of the solar power at the Observatory, as measured by Black-bulb readings.

According to the rule laid down by Mr. Stow in the Proceedings, Vol. IV, p. 304, the excess of the maximum temperature indicated by these blackened bulb thermometers, over the maximum temperature recorded in the shade, is taken as the amount of solar radiation for the day.

The subject of the measurement of solar radiation having been brought to the notice of the Kew Committee, one of the members suggested the use of a form of the instrument somewhat different to that ordinarily employed; and an experimental thermometer having been constructed for me by Mr. Hicks, readings were made of it daily for several months during the summer of 1878.

A comparison of these readings with those of the black bulbs led my friend and coadjutor Mr. Baker to remark that the indications of the latter were to a large extent influenced by the duration of sunshine, whilst I was more inclined to conclude that the relation of the two phenomena to one another would be one of cause and effect, and that a day of intense solar radiation would probably be followed by a clearer sky.

I also found that Mr. Stow had determined experimentally that the temperature of the black-bulb thermometer is raised unduly, on partially clouded days, and he assigned as the cause that the sun's heat reflected from the surface of bright cumulus clouds, being composed of rays of high refrangibility, easily passes through the glass jacket, and is absorbed by the black bulb, whilst the corresponding rays reflected from the ground on to the instrument, being rays of dark heat, are unable to penetrate the glass. With a view of submitting the question to proof, I plotted down as curves first the black bulb readings and the hourly duration of sunshine for each day, and then added the curve for solar radiation. It was at once evident there was a close relation between the phenomena of solar radiation and sunshine, but owing to the great range of the black-bulb thermometer the exact nature of the connection was not immediately apparent.

On examining the observations a source of difficulty was found in the method of registering the temperatures. The custom is to set the instruments daily at 10 a.m., and to enter their readings as the maximum black-bulb temperature for the previous day; hence there is an uncertainty as to whether the

TABLE I.
Duration of Sunshine, Reading of Black-Bulb Thermometer *in vacuo*, and Amount of Solar Radiation.

Day.	January.		February.		March.		April.		May.		June.		July.		August.		September.		October.		November.		December.	
	Sun.	Sol. Rad.	Sun.	Sol. Rad.	Sun.	Sol. Rad.	Sun.	Sol. Rad.	Sun.	Sol. Rad.	Sun.	Sol. Rad.	Sun.	Sol. Rad.	Sun.	Sol. Rad.	Sun.	Sol. Rad.	Sun.	Sol. Rad.	Sun.	Sol. Rad.	Sun.	Sol. Rad.
1	0.0	70.22	0.0	70.22	0.0	51.0	0.0	51.0	0.0	51.0	0.0	51.0	0.0	51.0	0.0	51.0	0.0	51.0	0.0	51.0	0.0	51.0	0.0	51.0
2	0.1	69.20	1.4	81.32	1.9	79.31	1.3	104.48	2.2	95.47	4.3	118.53	4.3	128.60	7.6	131.63	6.2	127.66	5.4	109.49	4.6	100.45	2.8	80.34
3	0.0	66.17	3.8	94.45	0.0	83.33	1.3	108.80	2.8	100.51	7.3	132.63	7.0	133.63	7.6	132.63	5.5	124.63	5.4	102.43	5.0	99.46	1.7	71.25
4	0.0	74.23	3.8	88.40	1.6	89.41	2.0	109.80	4.4	104.56	9.4	133.63	8.3	133.63	7.7	133.63	6.2	120.59	4.5	102.43	3.2	98.45	1.1	62.16
5	0.7	75.24	2.4	87.38	1.7	92.47	3.3	112.56	7.9	109.60	6.0	131.66	8.8	133.63	8.7	133.63	6.0	101.60	3.1	102.43	4.7	101.47	0.0	53.8
6	1.0	81.30	0.1	84.32	2.3	90.47	4.3	111.49	10.3	113.60	6.0	131.66	8.8	133.63	6.1	125.61	8.6	118.55	2.1	98.39	2.2	88.33	0.0	59.11
7	0.3	70.19	1.9	95.42	3.1	91.50	3.2	103.49	10.5	114.55	6.7	133.66	8.2	126.63	4.7	123.50	5.8	115.53	2.1	98.39	1.7	86.28	0.0	65.17
8	0.6	78.27	1.9	88.34	3.4	95.54	1.8	95.39	8.9	120.87	9.7	134.63	5.4	126.63	5.4	123.54	3.6	115.53	3.0	98.42	2.0	85.28	1.7	78.28
9	0.3	63.14	1.8	90.38	3.5	95.55	0.6	94.38	7.8	124.63	6.1	133.66	5.6	126.63	7.3	128.59	2.4	114.52	3.9	105.51	2.0	98.42	3.4	81.33
10	0.3	59.12	2.2	91.38	4.4	94.53	1.0	99.42	5.3	126.63	11.2	134.66	5.7	127.56	6.2	126.59	2.4	116.52	3.9	105.51	3.1	102.47	1.7	71.26
11	0.3	52.10	2.3	93.39	4.0	91.47	2.8	106.52	3.0	122.61	8.4	136.66	7.9	130.56	6.2	126.60	3.5	117.51	5.3	104.50	2.6	100.45	1.0	68.24
12	0.7	58.18	2.3	92.39	3.4	92.45	2.8	106.53	2.3	116.57	5.0	130.58	7.4	130.58	5.0	126.59	3.4	115.49	5.3	106.49	2.3	91.39	1.9	65.20
13	2.4	69.26	0.4	79.27	0.4	88.37	2.1	105.52	1.4	109.51	4.8	127.58	5.4	131.60	5.5	130.59	2.5	109.44	4.9	107.47	3.9	89.38	3.3	79.33
14	2.1	75.30	0.3	83.31	0.8	93.42	0.9	106.52	3.4	116.57	6.6	131.60	6.1	131.60	6.4	131.58	1.6	106.41	4.0	109.46	2.4	80.29	2.3	70.27
15	1.8	81.33	2.6	84.34	3.1	98.47	0.6	103.51	3.3	116.50	9.4	132.55	4.0	129.61	6.4	131.58	1.6	106.41	4.0	109.46	2.4	80.29	2.3	70.27
16	0.1	73.26	3.1	97.48	4.6	105.58	1.9	103.51	4.6	122.63	8.2	132.56	1.5	115.52	8.3	135.62	3.5	112.48	4.9	105.46	2.7	83.29	1.5	66.21
17	0.0	66.15	3.1	97.48	6.3	107.60	1.3	88.42	4.6	122.63	8.2	132.56	2.4	111.48	6.9	133.62	4.5	117.55	4.9	102.47	2.0	82.28	0.1	63.16
18	0.0	60.7	2.6	98.50	5.3	105.59	3.6	81.45	4.0	121.64	8.5	133.55	2.7	122.56	5.7	133.61	2.7	104.45	5.1	100.50	2.6	88.36	1.6	71.23
19	0.0	64.13	3.3	96.49	3.5	96.52	4.3	95.46	4.0	111.55	7.9	133.56	6.3	127.60	5.1	132.57	1.7	100.45	4.5	101.49	1.5	85.36	1.6	61.17
20	0.9	73.23	4.1	94.49	1.2	89.46	4.3	105.53	0.9	105.50	6.6	133.57	7.8	133.64	6.6	134.60	2.8	101.45	3.4	100.44	1.0	83.34	0.0	49.6
21	1.0	77.31	2.7	90.46	1.5	88.45	3.6	108.54	0.5	96.43	6.0	132.58	8.2	127.59	9.0	135.62	2.8	101.45	3.4	100.44	2.2	86.36	0.0	53.7
22	3.0	84.39	3.2	91.49	3.2	96.51	4.1	113.59	0.7	98.46	5.2	133.63	4.6	122.54	10.5	132.61	6.4	113.56	0.3	99.42	3.0	88.36	1.1	64.16
23	3.6	86.41	3.0	91.46	5.3	106.58	7.4	121.65	0.4	97.45	7.9	131.64	4.1	121.53	10.0	127.61	5.5	116.60	2.9	104.42	3.0	88.36	1.5	69.31
24	3.6	86.38	2.7	93.45	5.7	111.62	6.4	111.58	3.1	108.53	8.2	134.68	5.4	126.57	7.4	116.53	3.3	112.56	2.5	89.35	3.0	86.38	1.5	69.31
25	3.5	83.37	2.1	89.39	4.2	111.59	1.2	90.41	6.9	124.61	7.5	131.65	6.2	129.59	1.1	104.40	4.0	115.54	3.7	85.30	2.6	82.37	3.3	73.32
26	1.9	72.25	2.8	92.46	3.7	111.59	1.2	90.41	6.9	124.61	7.5	131.65	6.2	129.59	1.1	104.40	4.0	115.54	3.7	85.30	2.6	82.37	3.3	73.32
27	2.3	74.28	5.4	91.50	4.2	111.59	1.2	90.41	6.9	124.61	7.5	131.65	6.2	129.59	1.1	104.40	4.0	115.54	3.7	85.30	2.6	82.37	3.3	73.32
28	1.1	76.27	6.0	92.52	4.7	116.62	0.5	92.42	8.3	123.63	10.3	133.59	7.0	134.62	5.2	118.49	2.1	94.36	3.7	85.30	2.6	82.37	3.3	73.32
29	2.5	89.38	...	...	3.9	117.62	0.7	93.43	8.5	124.64	9.6	133.59	7.1	134.59	7.0	128.63	3.9	108.48	2.6	95.37	2.7	85.35	1.4	74.31
30	2.1	83.35	...	...	3.5	113.58	0.7	94.46	6.1	120.59	6.8	133.60	10.7	139.58	8.1	129.63	5.2	111.49	2.5	95.37	2.3	82.35	0.5	74.27
31	1.4	73.25	...	...	3.0	110.50	...	...	3.0	110.50	...	...	8.4	139.57	8.8	128.67	...	...	4.8	102.45	...	...	2.1	77.26

temperature registered really occurred on the day credited with it or on the next. As a means to some extent of removing these irregularities, I have adopted the plan of smoothing the curve by taking 8-day means, and entering them as the values for the middle day. Although this system of dealing with observations may be objected to, yet I may claim in its favour the success which has attended its introduction in rainfall and other investigations.

Table I. (p. 144) gives the values so obtained for every day of the year 1877, and the diagram represents the three phenomena plotted down in curves for each month.

It has been found necessary to treat the months separately, for several reasons. In the first place, the summer variations in temperature, being so much larger than those observed in winter, require to be represented on a smaller scale; and secondly, owing to seasonal change, the zeros of the several scales have to be shifted in order to bring the curves into juxtaposition.

A glance at the curves shows that the three phenomena are intimately connected with each other, the curves rising and falling together almost all through the year. There is only one important exception to this rule, viz. in the case of a rise in the readings of the black-bulb thermometer early in May, some four days subsequent to the maximum duration of sunshine for the period. This variation is so marked a deviation from the general behaviour of the curves, that I can only attribute it to erroneous readings, or to the prevalence of cloud of a peculiar nature as regards the transmission of heat rays. It would be possible to determine from the curves a series of constants, by means of which the amount of solar radiation might be approximately determined from the number of hours of sunshine on any day; but I have thought it better to wait for the results of several years' observations before attempting to fix these values.

Summarising the observations, we have in Table II. (p. 146) for every month, and also for one year, the comparisons of the times of occurrence of maxima and minima of both radiation and black-bulb curves as compared with the sunshine curves.

From this Table we find that, taking both maxima and minima into consideration, there were 70 cases of agreement between the solar radiation and sunshine in their times of occurrence, and 6 of disagreement, whilst the former phenomenon preceded the latter by a short interval 10 times, and succeeded it 16 times. The black bulb and sunshine duration agreed in 62 dates against 7 dates of opposition, and the thermometer curve advanced before the sunshine on 18 occasions and lagged behind it on 14.

I think it may therefore be safely concluded that the measure of solar radiation at any place, as given by the black-bulb thermometer, is only to be considered as an indication of the relative presence or absence of cloud from the sky at the locality, and so its use as a meteorological instrument may with advantage be set aside in favour of the sunshine recorder, which is not influenced by the elements of uncertainty inseparable from the former instrument.

I have to express my thanks to the Meteorological Council for permission

TABLE II.—Solar Radiation and Black Bulb Temperatures for 1877. Time of occurrences as compared with those of Sunshine duration.

Month.	Solar Radiation.						Opposed.	Black Bulb Thermometer.						Opposed.
	Maximum.			Minimum.				Maximum.			Minimum.			
	Before.	Same Date.	After.	Before.	Same Date.	After.		Before.	Same Date.	After.	Before.	Same Date.	After.	
January	..	5	1	..	4	..	..	3	1	..	3	..	1
February	1	4	..	..	2	..	1	2	3	1	2	..	1
March ..	..	3	1	1	2	1	..	1	2	1	2	1	..
April	1	3	1	..	4	..	2	1	2	..	3	..	1	
May ....	..	3	1	..	4	..	1	2	1	..	4	..	1
June	1	1	1	..	1	1	2	..	2	..	1	1	2	
July	2	2	1	1	1	3	..	2	2	1	2	1	2	
August ..	..	3	..	..	3	..	..	2	2	..	4	..	..
September	..	3	1	..	3	2	..	1	2	1	2	2	..	
October ..	1	4	..	..	3	..	..	1	4	..	3	..	1
November	..	3	1	..	4	1	..	..	3	..	5	1	..
December	..	2	..	..	4	..	..	..	2	..	4	..	..
Totals ..	6	36	8	4	34	8	6	12	28	7	6	34	7	7

to make use of their observations in this paper, and to Mr. Foster for kind assistance in preparing the diagrams illustrating it.

DISCUSSION.

Mr. BROOKE asked whether the differences in April and May were not due to the air temperature.

PROFESSOR ARCHIBALD wished to know why Mr. Whipple had taken 3-day means instead of the actual daily observations; adding that such a plan tended to eliminate many small irregularities from the curves, whose presence might either add to or detract from the number of corresponding points at present visible.

Mr. WHIPPLE said that from the circumstance of the thermometers being read at 10 a.m. he could not always tell to which day the readings belonged: at first he plotted down the daily observations, but the curves were so rough that he had to adopt this process to smooth them down, and to make them appear in an intelligible form.

Mr. GASTER asked at what time the observations of the maximum temperature in the air were read, those in the sun being read at 10 a.m.? Referring to ordinary observers, he could not conceive why, as the observers had to read the dry and wet bulb thermometers twice a day, they could not read the maximum and minimum thermometers also at both times. They would then be astonished to find how often in winter the maximum occurred during the night and the minimum during the day, nor could they fail to observe the deep significance of such occurrences.

Mr. WHIPPLE replied that the maximum temperature of the air was observed at 10 p.m.

Mr. SYMONS was surprised to hear that the shade thermometers were read at 10 p.m., and the solar instruments at 10 a.m. He thought that if observations of the solar thermometers were taken every hour, and compared with the sunshine record, some good results might be obtained; until this was done it would not be possible to decide which was the better instrument.

Mr. SAWYER thought that it was desirable to check the recorder by estimating the duration of sunshine according to the Scotch method. He also considered that the smoke from London would have some effect on the radiation at Kew.

Mr. WHIPPLE said that a very thin cloud intercepted the sun's rays, and

stopped the registration of the instrument. The custom at Kew in determining the duration of sunshine, was only to count the time of the actual burning of the card.

Mr. ELLIS remarked that *very* thin cloud in front of the sun did not stop the register at Greenwich. Generally speaking registration might be said to cease when the sun could be looked at without pain. In reports it was specified that the register was that of *bright* sunshine. Any trace undoubtedly made by the sun was counted.

PROCEEDINGS AT THE MEETINGS OF THE SOCIETY.

JANUARY 15th, 1879.

Ordinary and Annual General Meetings.

CHARLES GREAVES, M.Inst.C.E., F.G.S., President, in the Chair.

WILLIAM CAREY COLES, M.D., Bourton-on-the-Water ;
 WILLIAM WYMOND HAMLEY, M.A., Clare College, Cambridge ;
 CHARLES EDWARD HARRIS, Tylney Hall, Winchester ;
 HENRY B. JOYNER, San Paulo, Brazil ;
 WILLIAM JONES LLOYD, M.A., D.L., Langlebury, Watford ;
 J. H. MCCLURE, F.R.G.S., Beaconsfield Club, Pall Mall, S.W. ;
 GRAYSON MADDERS, M.R.A.S., Grosvenor Terrace, Richmond ;
 JAMES MONKS, Ader Cottage, Durham ;
 EDWARD CHAPMAN MORRELL, Broughton, Banbury ;
 EDWARD MURPHY, Dunfanaghy, Letterkenny, Ireland ;
 GEORGE HENRY NELSON, The Lawn, Warwick ;
 G. F. NORTH, Cheswardine, Market Drayton ;
 T. PAIN, The Grove, Basingstoke ;
 PICKERING PHIPPS, M.P., Northampton ;
 THOMAS RIGBY, Sutton Mill, Preston Brook, Cheshire ;
 ARCHIBALD ROGERS, 41 Parliament Street, S.W. ;
 WILLIAM SCOTSON, Rose Lane, Aigburth, Liverpool ;
 HENRY TOWNSEND, Caldicote Hall, Nuneaton ;
 THOMAS JOHN TURNBULL, Wimborne St. Giles, Dorset ; and
 HERBERT SOWERBY WALLIS, 1 Springfield Road, St. John's Wood, N.W.,
 were balloted for and duly elected Fellows of the Society.

The PRESIDENT then declared the Ordinary Meeting closed, and announced that the Annual General Meeting had commenced.

Mr. C. HARDING and Mr. M. JACKSON were appointed Scrutineers of the Ballot for Officers and Council.

Dr. TRIPE read the Report of the Council and the Financial Statement for the past year. (p. 113.)

It was proposed by the PRESIDENT, seconded by Mr. EATON, and resolved :—
 "That the Report just read be received and adopted, and circulated among the Fellows."

It was proposed by Dr. TRIPE, seconded by Mr. DYMOND, and resolved :—
 "That the cordial and best thanks of the Society be communicated to the Council of the Institution of Civil Engineers, for having granted the Society free permission to hold the Meetings in the Rooms of the Institution, and also for the use of the Theatre for the Lectures."

It was proposed by Mr. SCOTT, seconded by Mr. SYMONS, and resolved :—
 "That the thanks of the Society be given to the President for the ability and