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## XVI. *Solar Radiation.—An account of some Experiments made at Harpenden, Herts.* By the Rev. FENWICK W. STOW, M.A., F.M.S.

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THE chief object of these experiments was to ascertain approximately the limits of error in the plan for measuring Solar Radiation which the author had previously submitted to the Society. He then proposed to expose freely to the sun and air, at 4 feet above the ground, a thermometer *in vacuo*, with the bulb and 1 inch of the stem blackened, the bulb being directed to the south-east, and to consider the excess of its readings above those of an ordinary thermometer in the shade, at the same height from the ground, to be the amount of solar radiation. Observations on this plan have been received from about a dozen stations.

The experiments consisted partly in a comparison of the measure of solar intensity thus furnished with those obtained by a Herschel's actinometer, and by other means, and partly of experiments with similar sets of different thermometers exposed under different conditions, in order to throw some light on the question what the words "Sun" and "Shade" should be held to mean, at least for the purpose of measuring solar radiation. The latter are detailed in a separate paper.

In Table I. the results of comparison with the Herschel's actinometer are given. The observations were taken towards the end of September, 1872, when the weather was not at all favourable for the purpose, there being very little steady sunshine; while the rapid fluctuations in the rate of cooling, caused by fitful breezes, rendered the change per minute very uncertain when the actinometer was used with the glass off. It is doubtful whether the use of a fluid so variable in its dilatability as ammonio-sulphate of copper is desirable; nor is it likely that the inclosed thermometer shows the mean temperature of the whole liquid at the moment of observation with any approach to exactness; and yet an error of 1° will generally make an error of 2 per cent. in the corrected results. Probably the actinometers invented by Mr. Hodgkinson, and described in the 'Proceedings of the Royal Society,' vol. xv. p. 321, are more satisfactory, since alcohol is the fluid used. The author had experienced also some difficulty in shading the instrument, without altering the conditions of cooling from those which existed during its exposure to the sun; but in the face of these difficulties it is satisfactory to find that the ratio between the indications of the two instruments fluctuated, on an average, less than 2 per cent. for the higher numbers, and 3 per cent. throughout, except in the case of observations taken when the sun was just setting. This is the more satisfactory, because the blackened bulb *in vacuo* receives the heat reflected from the clouds on all sides, whereas the actinometer can, from its construction, admit only what comes from clouds near the sun; and variations in the indications of the two instruments are necessarily thus introduced according as the state of the sky changes.

It seems therefore that whenever a standard unit of solar intensity exists, observations made according to this method, with the blackened bulb *in vacuo* at 4 feet above the ground, or at whatever height the shade thermometers are placed, will give results reducible to such units.

But, putting an absolute standard, such as that obtained by the melting of ice, out of the question, he thought that the total elevation of temperature which a blackened bulb *in vacuo* experiences above the temperature of its surroundings, before equilibrium is established between the heating energy of the solar rays and the forces which tend to cool the bulb, is a better measure of radiation, and more suitable for a standard than the rise per minute of a liquid in a tube. He was not, however, prepared at present to say how such a standard should be made. Possibly an apparatus like Padre Secchi's, but larger and mounted equatorially, might be advisable, the sun's rays being admitted through a piece of rock-salt, or other crystal, and as perfect a vacuum as possible obtained inside.

He must here express his thanks to Mr. Wilson for assistance in taking the observations, to Mr. Eaton for giving the benefit of his experience in the use of actinometers, and to Mr. Nunes* for help in some of the experiments, and for the loan of the instruments.

He might also briefly mention that he tried a Pouillet's pyrheliometer; but its extreme sluggishness, which renders a long exposure necessary, demands steady and long-continued sunshine. He was unable therefore to compare it satisfactorily with any other instrument.

Another measure of solar radiation might be obtained by the blackened bulb *in vacuo*, by taking the excess of its readings above those given by a bright unblackened bulb, also *in vacuo*. This plan would have the important advantage for ordinary registration of securing that the maxima shown by the two instruments should be simultaneous, which is not generally the case when the maximum shade-temperature is employed. The maximum in the sun generally occurs soon after noon; that in the

* This was written before Mr. Nunes's lamented death.

shade at least an hour later. Nevertheless it will be seen by a comparison of the two methods, made at Hawsker in 1871 (Table II.), that the ratio of the numbers obtained by the two methods was found nearly constant, except in very cloudy weather.

Nearly all the blackened-bulb thermometers *in vacuo* used by the author's correspondents have been compared with his own in the sun. Of these, two agree exactly with his own, five more within 1°, three within 2°; but one reads 4°·5 in excess, when the amount of solar radiation is 50° by his instrument. It is certainly necessary to compare them in the sun. The lampblack is generally applied with a varnish, and sufficient care is not always taken to have the bulb perfectly dull; imperfections in the vacuum sometimes occur, and differences in the thickness of the glass are inevitable. Another fact has generally been overlooked, viz. that the index-error is altered by the removal of atmospheric pressure, most of these instruments reading 0°·5 too low. In some careful experiments by Mr. Benjamin Loewy, F.R.A.S. (reported, vol. xvii. p. 319 of the 'Proceedings of the Royal Society'), the behaviour of thermometers in a vacuum was investigated. It was found that although the immediate effect of exhaustion diminished after a time, the reading of a thermometer in a vacuum was permanently depressed, and further, that thermometers with small bulbs were more affected than those with larger bulbs, because the glass was thinner. It would be well if solar thermometers were compared at Kew, both in the sun and in water, after enclosure and exhaustion.

Mr. Nunes had proposed to admit dry air into the jackets of these instruments. The indications are thereby rendered less sensitive, since the point of equilibrium is very much lowered by the rapid cooling consequent on the presence of air. Errors arising from the use of instruments with vacua of different degrees of imperfection are got rid of; but, on the other hand, a pressure depending on temperature is introduced.

Table III. contains a comparison of the two kinds of instruments. Mr. Nunes had a pair of thermometers specially constructed by Mr. Casella, with very large bulbs (0·6 inch diam.). They were similar in every respect, except that chemically dried air was admitted into the glass jacket of one of them. These were compared with a pair similarly made by the same maker, but with bulbs of half the diameter; and Mr. Pastorelli supplied a pair of dry-air instruments, one having a bulb about 0·35 inch diam., and the other 0·5 inch. Days on which the sunshine was pretty steady were selected, to eliminate as far as possible the great difference in the sensibility of large and small bulbs. It will be seen that the two thermometers *in vacuo* both agreed more closely, and exhibited fewer irregularities, than the dry-air instruments. The blackened bulb, being much hotter than the enclosed air, imparts to it a quantity of heat depending upon its own size and the volume of the enclosed air; and if this air be hotter, the temperature which the bulb attains in the sun will evidently be higher. A larger bulb or smaller jacket will therefore cause a higher temperature to be indicated. This is exactly what was found to be the case. The large bulb, in dry air, by both makers gave a higher reading than the small bulb; but, as the jackets of Pastorelli's thermometers were smaller, each of these instruments read higher than the corresponding one of Casella's. (See Table IV.)

In the case of thermometers *in vacuo*, when the unequal loss of heat by conduction is got rid of by extending the lampblack to the stem, the only remaining sources of error are the mere accidents or imperfections of construction. True, considerable differences are sometimes observed in the indications of these instruments; but these are exceptional, and in any case it is easy to compare the instruments and allow for them.

Table V. shows the results obtained by exposing a blackened bulb to the sun's rays under the exhausted receiver of an air-pump. The bulb of the instrument was placed about 2 inches from the top of the receiver, and observations were taken on two days. On the second day the apparatus had been exposed for some time to the sun before the observations were made, and the plate on which the receiver rests had become heated, which may account for the readings being relatively higher. But, in spite of the diversity of conditions, including a considerable difference in the thickness of the glass, there was a near approximation between the indications of this instrument and those of a solar thermometer of the ordinary construction.

It would be an improvement to have an attached or inserted thermometer, contrived to show the temperature of the outer jacket, and to use this, or the reading of a thermometer *in vacuo* with unblackened or, still better, silvered bulb exposed to the sun's rays, instead of the temperature of the air in the shade. But, even as it is, observations made on the system suggested four years ago are scarcely, if at all, inferior to observations taken with a Herschel's actinometer, and valuable results might surely therefore be thus obtained.

To look at the subject generally, there are three different objects which meteorologists may propose to themselves in attempting to measure the sun's heat. The first is the measurement of the intensity of the solar rays, irrespectively of the duration of sunshine and of the angle at which the rays strike the ground. The second is the total heating effect upon a large mass of earth, metal, or water, also irrespectively of the angle of incidence of the sun's rays, but depending both upon the intensity and the duration of the sunshine. This might be measured by inserting a thermometer into the centre of a hollow sphere, such as a 68-lb. shell, which might be filled with water, and should be elevated above the ground. The third is the heating effect produced upon the earth's surface, depending upon the altitude of the sun, as well as upon intensity and duration of sunshine, not to mention moisture, evaporation, &c. This may be measured by a thermometer, not *in vacuo*, placed upon the ground, or still better perhaps, by one buried just below the surface of a level sand-bed.

It is to the first of these, Actinometry, that he has directed attention. The author does not say that the other investigations are not equally important; but he thinks it best to obtain figures which represent the action, not of a variety of causes, the individual effect of each of which is unknown, but of one cause only, and afterwards to proceed to the investigation of the effects of two or more causes combined. Thus, supposing that a measure of solar radiation or intensity is first obtained, and then results involving both intensity and duration discussed. These being both known, the third investigation might be approached where the sun's altitude and other causes are also involved. It might be even worth while to attack the complication of causes to which the temperature of a black bulb *in vacuo* on the grass is due. But the present system is to jumble together every species of heterogeneous observations depending upon all possible causes, known or unknown, and to call these by the one name of the "maximum in the sun." It is to be hoped that if this Society is to have any thing to do with publishing meteorological observations, it will not sanction any such chaotic arrangements, but insist on a uniform system of meteorological observations of all kinds, and not publish those taken on a different system.

It is not known that the heat emitted from the sun is constant in amount. Very possibly it is not, but has a secular variation. This will be one of the most interesting points to be determined. A cycle corresponding to the eleven years' sun-spot period has been thought to appear in the Oxford observations of solar radiation. With more strictly actinometrical observations this question will easily be determined. The further question, however, will remain, whether such periodicity is due to more heat being emitted from the sun, or to less being intercepted by the atmosphere. Scarcely any thing is known as yet about the absorption of the sun's heat by the atmosphere. From the intensity of solar radiation on high mountains it may be concluded that the percentage absorbed, especially by the moist cloud-stratum, is very large. It is certainly subject also to extensive fluctuations.

The amount of solar radiation often varies inversely as the temperature of the air, a fact which seems to lie at the very root and starting-point of meteorology. If the Society would practically take up solar-radiation investigations it might hope to find the key to many unsolved problems. Good observations should be made and thoroughly discussed. In conclusion, the author will be more than content if he has succeeded in pointing out the means by which, in any one particular, valuable observations may be made.

TABLE I. Comparison of Actinometer with "Blackened-bulb Thermometer *in vacuo*" or Solar Thermometer.

| Date, 1872. | Time. | Sun ⊙, or shade ×. | Actinometer. | | | | | Solar Thermometer. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial reading. | Terminal reading. | Temp. of liquid. | Sun's effect per min. | Ditto reduced to 60° F. | Reading at time in sun's rays. | Temp. of air in shade. | Diff. = amount of radiation. |
| Sept. | h m s | | | | ° | | | ° | ° | ° |
| 16 | 3 59 | × | 67·5 | 57·5 | | | | | | |
| | | ⊙ | 58 | 74 | 78 | 26 | 19·7 | 98 | 62·8 | 35·2 |
| 19 | 23 58 30 | × | 27·2 | 28 | 77 | | | | | |
| 20 | Noon. | ⊙ | 41 | 80 | | 37·2 | 38·9 | 106·5[a] | 50 | 56·5 |
| " | 0 1 30 | × | 88·5 | 91·2 | 59 | | | | | |
| " | 0 4 | ⊙ | 28 | 63·2 | 60 | 35·4 | 35·4 | 108 | 50 | 58 |
| " | 0 6 30 | × | 44 | 41 | ... | | | | | |
| " | 0 8 | ⊙ | 4·8 | 41 | | 39·2 | 37·7 | | | |
| " | 0 9 30 | × | 46 | 43 | 63 | ... | ... | 109·5 | 50·5 | 59 |
| " | 0 12 | ⊙ | 43 | 76·5 | 63·5 | 37·5 | 34·9 | | | |
| " | 0 13 30 | × | 82 | 78 | 64 | ... | ... | 111·5[b] | 51 | 60·5 |
| " | 0 45 | × | 28·5 | 21·5 | ... | | | | | |
| " | 0 46 30 | ⊙ | 29·2 | 57·5 | 65 | 35·4 | 32·1 | 105 | 52 | 53 |
| " | 0 49 | × | 53·8 | 46·5 | ... | | | | | |
| " | 1 4[c] | × | 22·5 | 14 | 65 | | | | | |
| " | 1 6 30 | ⊙ | 40 | 63·5 | 66 | 32 | 28·5 | 103·5 | 51·5 | 52 |
| " | 1 8 | × | 65 | 56·5 | ... | ... | ... | 104 | 52·5 | 51·5 |
| " | 1 9 30 | ⊙ | 61·5 | 84 | ... | 31·7 | 27·8 | 105 | 52·8 | 52·2 |
| " | 1 12 | × | 25 | 15 | 67·5 | | | | | |
| " | 1 16 | × | 33·5 | 25 | 66·5 | | | | | |
| " | 1 18 | ⊙ | 25 | 48·2 | ... | 31·9 | 28 | 107 | 52·8 | 54·2 |
| " | 1 19 30 | × | 48 | 39 | 67·5 | | | | | |
| " | 1 21[c] | ⊙ | 41 | 67 | 68 | 35 | 30·1 | 108·2 | 53·3 | 54·9 |
| " | 2 41 30 | × | 34·5 | 4·5 | | | | | | |
| " | 2 43 | ⊙ | 37·8 | 41·5 | 77 | 32·3 | 25·0 | 97·5 | 53·3 | 44·2 |
| " | 2 45 | × | 75·5 | 48·2 | 76 | | | | | |
| " | 3 25 | × | 32 | 25·3 | | | | | | |
| " | 3 26 30 | ⊙ | 28·5 | 40·5 | 63 | 18·7 | 17·6 | 81·5 | 51 | 30·5 |
| " | 3 31 | × | 49·5 | 41·4 | | | | | | |
| " | 3 34 | ⊙ | 59·7 | 73 | 64 | 21·5 | 20 | | | |
| " | 3 35 30 | × | 73·5 | 65·3 | ... | ... | ... | 81 | 51·2 | 29·8 |
| " | 3 38 | ⊙ | 61 | 75·8 | ... | 23 | 21·4 | 84 | 51·5 | 32·5 |
| " | 3 40 30 | ⊙ | 32·8 | 47·5 | 64 | 23·7 | 22 | 86·5 | 51·5 | 35 |
| " | 3 42 | × | 47 | 38 | | | | | | |
| " | 3 43 30 | ⊙ | 41·8 | 57·8 | 64 | 24·4 | 22·7 | 88 | 51·8 | 36·2 |
| " | 3 46 | × | 55 | 47·2 | | | | | | |
| " | 3 47 30 | ⊙ | 47·8 | 63·8 | 64 | 23·7 | 22 | 89 | 52·2 | 36·8 |
| " | 3 49 | × | 64·5 | 57 | | | | | | |
| " | 3 52 | ⊙ | 52·2 | 67·2 | ... | 22·8 | 21·2 | 89·5[d] | 52·2 | 37·3 |
| " | 3 54 | × | 72·5 | 64·5 | 64·5 | | | | | |
| " | 3 55 30 | ⊙ | 64·5 | 79·5 | | | | | | |
| " | 5 4 | × | 28 | 22·8 | 60 | | | | | |
| " | 5 5 30 | ⊙ | 22·5 | 25·2 | ... | 8·8 | 8·8 | 66 | 49·3 | 16·7 |
| " | 5 7 | × | 23·5 | 16·5 | 60 | | | | | |
| " | 5 8 30 | ⊙ | 16·5 | 18 | ... | 8·7 | 8·7 | 65 | 49 | 16 |
| " | 5 10 | × | 16·5 | 9·1 | 59·5 | | | | | |
| " | 22 38 | × | 50 | 54·5 | 55 | | | | | |
| " | 22 39 30 | ⊙ | 66 | 99 | ... | 28·5 | 30·8 | 101[a] | 52·2 | 48·8 |
| " | 22 42 30 | × | 10·3 | 13 | 58 | | | | | |
| " | 22 44 | ⊙ | 27 | 65 | ... | 35·9 | 36·6 | 105·5[a] | 53 | 52·5 |
| " | 22 45 30 | × | 72 | 73·5 | ... | ... | ... | 106·5[a] | 53 | 53·5 |
| " | 22 47 | ⊙ | 10·8 | 48·2 | 60·5 | 36·2 | 35·9 | 108·5 | 54 | 54·5 |
| " | 22 48 30 | × | 12·8 | 13·8 | ... | ... | ... | 109·5 | 54 | 55·5 |
| " | 22 50 | ⊙ | 22·2 | 41·5[f] | ... | 37·6 | 37 | 111·2 | 54 | 57·2 |
| 22 | 20 23 | × | 52·8 | 56·6 | | | | | | |
| " | 20 24 30 | ⊙ | 66 | 92·5 | 59 | 24·4 | 24·9 | 90 | 44·5 | 45·5 |
| " | 20 26 | × | 49 | 49·4 | | | | | | |

[a] Solar thermometer still rising. [b] Cloud very near to the sun.
[c] From $1^h\ 4^m$ to $1^h\ 21^m$ sun shining through haze and cirrus.
[d] Registered maximum. [f] Exposed only 30 seconds.

TABLE I. (*continued*).

| Date, 1872. | Time. | Sun ⊙, or shade ×. | Actinometer. | | | | | Solar Thermometer. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Initial reading. | Terminal reading. | Temp. of liquid. | Sun's effect per min. | Ditto reduced to 60° F. | Reading at time in sun's rays. | Temp. of air in shade. | Diff. = amount of radiation. |
| Sept. | h m s | | | | ° | | | ° | ° | ° |
| 22 | 20 28 | ⊙ | 31 | 57·2 | ... | 26·4 | 26·4 | 91 | 45·2 | 45·8 |
| ,, | 20 29 30 | × | 62 | 61·2 | 61 | | | | | |
| 24 | 20 3 | ⊙ | 65 | 86·3 | 57 | 24·1 | 25·7 | 83·5 | 43·5 | 40 |
| ,, | 20 4 30 | × | 91 | 88·2 | | | | | | |
| 28 | 21 15 | ⊙ | 28 | 58 | 65 | 31·5 | 28·6 | | | |
| ,, | 21 16 30 | × | 66 | 64·5 | ... | ... | ... | 101 | 56 | 45 |
| ,, | 21 18 | ⊙ | 39 | 66 | 67 | 31·5 | 28 | | | |
| ,, | 21 19 30 | × | 88 | 83·5 | ... | ... | ... | 101·2 | 56·2 | 45 |
| Oct. 6 | 23 50 | × | 51·2 | 60·6 | 55 | | | | | |
| ,, | 23 51 30 | ⊙ | 27·7 | 64·1 | 58 | 27·7 | 28·9 | 104·8 | 57·2 | 47·6 |
| ,, | 23 54 30 | × | 26.5 | 34·6 | 59 | ... | ... | 105 | 58 | 47 |
| ,, | 23 56 | ⊙ | 50·5 | 86·5 | 61 | 29·2 | 28·6 | | | |
| ,, | 23 58 | × | 38·5 | 44 | 61·5 | | | | | |
| 7 | 0 8 | ⊙ | 29·5 | 61·5 | 67 | 34·2 | 29·9 | | | |
| ,, | 0 9 30 | × | 65·2 | 63 | ... | ... | ... | 106·2 | 58·4 | 47·8 |
| ,, | 0 11 30 | ⊙ | 31 | 60·6 | 68 | 32·1 | 27·7 | | | |
| ,, | 0 13 | × | 66·3 | 63·4 | 68·5 | ... | | | | |
| ,, | 0 14 50 | ⊙ | 16·5 | 46·4 | 69·5 | 33·6 | 28·4 | 106·8 | | |
| ,, | 0 16 30 | × | 21 | 16·5 | 70 | ... | ... | ... | 58·4 | 48·4 |

TABLE I B. Comparable Observations arranged according to the Intensity of Solar Radiation by Actinometer.

| Date. | Time. | Actinometer. | Solar thermometer | | | | Actinometer. | Solar thermometer. | Mean ratio. A/B. | Average departure from mean ratio. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Sun's effect reduced to 60° F. A. | Solar thermometer at time. | Temp. of air in shade. | Diff. = amount of radiation. B. | Ratio. A/B. | Mean sun's effect. | Mean amount of radiation. | | |
| Sept. | h m | | ° | ° | ° | | | ° | | |
| 20 | 22 50 | 37 | 111·2 | 54 | 57·2 | ·65 | | | | |
| ,, | 0 9 | 36·3 | 109·5 | 50·5 | 59 | ·62 | | | | |
| ,, | 22 47 | 35·9 | 109 | 54 | 55 | ·65 | 35·3 | 56·4 | ·628 | ·018 |
| ,, | 0 4 | 35·4 | 108 | 50 | 58 | ·61 | | | | |
| ,, | 0 46 | 32·1 | 105 | 52 | 53 | ·61 | | | | |
| Oct. 7 | 0 8 | 29·9 | 106·2 | 58·4 | 47·8 | ·62 | | | | |
| 6 | 23 51 | 28·9 | 104·8 | 57·2 | 47·6 | ·61 | | | | |
| Sept. 28 | 21 15 | 28·6 | 101 | 56 | 45 | ·64 | 28·9 | 47·2 | ·614 | ·013 |
| Oct. 6 | 23 56 | 28·6 | 105 | 58 | 47 | ·61 | | | | |
| 7 | 0 15 | 28·4 | 106·8 | 58·4 | 48·4 | ·59 | | | | |
| Sept. 28 | 21 18 | 28 | 101·2 | 56·2 | 45 | ·62 | | | | |
| 22 | 20 28 | 26·4 | 91 | 45·2 | 45·8 | ·58 | | | | |
| 24 | 20 3 | 25·7 | 83·5 | 43·5 | 40 | ·64 | 25·6 | 42·2 | ·608 | ·026 |
| 20 | 2 43 | 25 | 97·5 | 53·5 | 44·2 | ·57 | | | | |
| ,, | 3 44 | 22·7 | 88 | 51·8 | 36·2 | ·63 | | | | |
| ,, | 3 48 | 22 | 89 | 52·2 | 36·8 | ·60 | | | | |
| ,, | 3 40 | 22 | 86·5 | 51·5 | 35 | ·63 | | | | |
| ,, | 3 38 | 21·4 | 84 | 51·5 | 32·5 | ·65 | 20·5 | 34 | ·604 | ·029 |
| 16 | 3 59 | 19·7 | 98 | 62·8 | 35·2 | ·56 | | | | |
| 20 | 3 26 | 17·6 | 81·5 | 51 | 30·5 | ·58 | | | | |
| ,, | 5 5 | 8·8 | 66 | 49·3 | 16·7 | ·53 | | | | |
| ,, | 5 8 | 8·7 | 65 | 49 | 16 | ·54 | | | | |

TABLE II. Comparison of difference of Blackened and Bright Bulbs *in vacuo* with difference of Blackened Bulb *in vacuo* and Air-temperature from observations made at Hawsker, near Whitby, 1871.

| Date. | Maxima. | | | c—b. | c—a. | Ratio. (c—b)/(c—a). |
|---|---|---|---|---|---|---|
| | Shade temp. a | Bright b. in vac. b | Black b. in vac. c | | | |
| | ° | ° | ° | ° | ° | |
| June 25 | 54·9 | 75 | 123 | 48 | 68·1 | ·70 |
| „ 21 | 54·1 | 74 | 120 | 46 | 65·9 | ·70 |
| „ 13 | 59·2 | 78·1 | 123·8 | 45·7 | 64·6 | ·71 |
| „ 22 | 54·3 | 74·5 | 120 | 45·5 | 65·7 | ·69 |
| „ 11 | 55 | 74 | 118·2 | 44·2 | 63·2 | ·70 |
| „ 4 | 52·5 | 72 | 116 | 44 | 63·5 | ·69 |
| „ 1 | 53·6 | 73 | 117 | 44 | 63·4 | ·69 |
| „ 3 | 50·2 | 69·2 | 112·2 | 43 | 62 | ·69 |
| July 20 | 62 | 81 | 124 | 43 | 62 | ·69 |
| June 5 | 53·5 | 74·3 | 117·2 | 42·9 | 63·7 | ·67 |
| July 23 | 65 | 85 | 127·5 | 42·5 | 62·5 | ·70 |
| June 2 | 49·8 | 67·2 | 108·8 | 41·6 | 59 | ·71 |
| „ 24 | 54·4 | 71·5 | 113 | 41·5 | 58·6 | ·71 |
| Aug. 6 | 67·7 | 86·8 | 127·8 | 41 | 60·1 | ·68 |
| May 26 | 61 | 78 | 119 | 41 | 58 | ·71 |
| June 18 | 66·2 | 84·5 | 125·3 | 40·8 | 59·1 | ·72 |
| May 25 | 65·6 | 79·2 | 120 | 40·8 | 54·4 | ·75 |
| July 25 | 62·2 | 83 | 123·5 | 40·5 | 61·3 | ·66 |
| „ 1 | 67·7 | 83·2 | 123·5 | 40·3 | 55·8 | ·72 |
| May 30 | 63·9 | 81 | 121·2 | 40·2 | 57·3 | ·70 |
| July 30 | 63·3 | 82 | 122 | 40 | 58·7 | ·68 |
| Aug. 21 | 65·2 | 82·2 | 122·2 | 40 | 57 | ·70 |
| June 27 | 62·6 | 78·8 | 118·8 | 40 | 56·2 | ·71 |
| July 22 | 66·5 | 85 | 124·8 | 39·8 | 58·3 | ·68 |
| May 29 | 54·8 | 72·7 | 112·5 | 39·8 | 57·7 | ·69 |
| „ 24 | 62·5 | 78·2 | 118 | 39·8 | 55·5 | ·72 |
| July 31 | 65 | 84 | 123·5 | 39·5 | 58·5 | ·68 |
| Aug. 2 | 70·8 | 89·8 | 129·2 | 39·4 | 58·4 | ·68 |
| „ 25 | 64·2 | 81 | 120 | 39 | 55·8 | ·70 |
| July 28 | 64·2 | 83·2 | 121·8 | 38·6 | 57·6 | ·67 |
| May 23 | 57 | 74·5 | 113 | 38·5 | 56 | ·69 |
| June 30 | 66 | 81 | 119·2 | 38·2 | 53·2 | ·71 |
| Aug. 14 | 68·1 | 84 | 122·2 | 38·2 | 54·1 | ·71 |
| „ 22 | 63·4 | 79 | 117·1 | 38·1 | 53·7 | ·71 |
| „ 16 | 65 | 82 | 120 | 38 | 55 | ·69 |
| July 26 | 62 | 75·5 | 113 | 37·5 | 51 | ·74 |
| Aug. 26 | 64 | 80 | 117 | 37 | 53 | ·70 |
| July 29 | 62·8 | 79·8 | 116·8 | 37 | 54 | ·69 |
| May 21 | 65 | 81 | 118 | 37 | 53 | ·70 |
| Aug. 1 | 67·8 | 83 | 120 | 37 | 52·2 | ·71 |
| „ 19 | 64 | 80·5 | 117 | 36·5 | 53 | ·69 |
| „ 13 | 67 | 84 | 120·5 | 36·5 | 53·5 | ·68 |
| May 27 | 54·8 | 70 | 106 | 36 | 51·2 | ·70 |
| Aug. 15 | 64·5 | 80 | 115·5 | 35·5 | 51 | ·69 |
| „ 11 | 81·2 | 96 | 131·2 | 35·2 | 50 | ·70 |
| July 27 | 65·2 | 83 | 118·2 | 35·2 | 53 | ·66 |
| Aug. 9 | 73 | 89 | 124 | 35 | 51 | ·69 |
| „ 8 | 69·4 | 86·8 | 121·5 | 34·7 | 51·5 | ·67 |
| „ 18 | 69 | 86 | 120·5 | 34·5 | 51·5 | ·67 |
| July 21 | 64 | 76 | 106·5 | 30·5 | 42·5 | ·72 |
| May 31 | 54·6 | 66 | 95·2 | 29·2 | 40·6 | ·72 |
| Aug. 12 | 77·8 | 92 | 121·8 | 28·8 | 44 | ·65 |
| June 19 | 61 | 72·5 | 101 | 28·5 | 40 | ·71 |
| Aug. 23 | 66·1 | 77 | 104·5 | 27·5 | 38·4 | ·72 |
| June 8 | 49·3 | 60 | 86·2 | 26·2 | 36·9 | ·71 |
| Aug. 17 | 65 | 72 | 95 | 23 | 30 | ·77 |
| May 28 | 50·9 | 59 | 79 | 20 | 28·1 | ·71 |
| Aug. 20 | 65 | 72 | 92 | 20 | 27 | ·74 |
| Sept. 18 | 52 | 58 | 77 | 19 | 25 | ·76 |
| June 20 | 54·9 | 58·8 | 71·2 | 13·4 | 16·3 | ·82 |
| Sept. 13 | 56 | 60 | 72 | 12 | 16 | ·75 |
| „ 12 | 57·2 | 61 | 70·5 | 9·5 | 13·3 | ·71 |
| „ 9 | 58·6 | 60 | 69 | 9 | 10·4 | ·86 |

TABLE III. Thermometers in Dry Air and *in vacuo*.

| Date, 1872. | Days of steady sunshine. | | | | | |
|---|---|---|---|---|---|---|
| | Large bulb *in vacuo*. L. | Small bulb *in vacuo*. S. | Diff. L—S. | Large bulb in air. L′. | Small bulb in air. S′. | Diff. L′—S′. |
| Diameter of bulb ...<br>Diameter of jacket... | 0·6<br>2·33 | 0·3<br>2·2 | ...<br>... | 0·6<br>2·32 | 0·3<br>2·26 | |
| July 7 .............. | 137·5° | 136° | 1·5° | 121·7° | 116·8° | 4·9° |
| „ 8 .............. | 116·8 | 116 | 0·8 | 102·7 | 101·3 | 1·4 |
| „ 10 .............. | 130·6 | 130 | 0·6 | 115·2 | 111·8 | 3·4 |
| „ 13 .............. | 127·5 | 126·1 | 1·4 | 111·5 | 106·8 | 4·7 |
| „ 18 .............. | 125·6 | 125·5 | 0·1 | 111·2 | 106·9 | 4·3 |
| „ 19 .............. | 129·1 | 128 | 1·1 | 114·2 | 110·6 | 3·6 |
| „ 20 .............. | 130·6 | 129·2 | 1·4 | 117 | 111·8 | 5·2 |
| „ 21 .............. | 138·4 | 137 | 1·4 | 124 | 119·3 | 4·7 |
| „ 22 .............. | 126·8 | 126·2 | 0·6 | 116·2 | 113 | 3·2 |
| „ 23 .............. | 131·7 | 131 | 0·7 | 118·2 | 113·8 | 4·4 |
| „ 25 .............. | 135·1 | 134·2 | 0·9 | 122·7 | 118·3 | 4·4 |
| „ 26 .............. | 134·6 | 133·2 | 1·4 | 123·7 | 120·8 | 2·9 |
| „ 27 .............. | 128·6 | 128·2 | 0·4 | 117·2 | 113·8 | 3·4 |
| „ 28 .............. | 125·1 | 124 | 1·1 | 108 | 103·8 | 4·2 |
| Aug. 3 .............. | 129·6 | 128 | 1·6 | 113 | 107·8 | 5·2 |
| „ 15 .............. | 122·6 | 122 | 0·6 | 107·2 | 104·8 | 2·4 |
| „ 18 .............. | 123·6 | 121·5 | 2·1 | 112·2 | 107 | 5·2 |
| „ 19 .............. | 129·6 | 126·8 | 2·8 | 115·2 | 110·3 | 4·9 |
| „ 20 .............. | 128·6 | 126·5 | 2·1 | 114·2 | 109·3 | 4·9 |
| „ 21 .............. | 135·8 | 134·2 | 1·6 | 120·2 | 115·8 | 4·4 |
| Mean .............. | 129·39 | 128·18 | 1·21 | 115·27 | 111·19 | 4·08 |
| Average deviation from mean...... | ... | ... | ·52 | ... | ... | ·83 |

TABLE IV. Comparison of four Blackened-bulb Thermometers in Glass Jackets containing Dry Air.

| Date. | Casella. | Casella. | Pastorelli. | Pastorelli. |
|---|---|---|---|---|
| Diameter of bulb ...<br>Diameter of jacket... | 0·6 in.<br>2·32 in. | 0·3 in.<br>2·26 in. | 0·5 in.<br>2·02 in. | 0·35 in.<br>2·0 in. |
| 1872. | | | | |
| Aug. 24.............. | 113·5° | 109·5° | 114·2° | 111·2° |
| „ 25.............. | 112 | 107·5 | 112 | 109 |
| „ 26.............. | 109·2 | 104·5 | 110·7 | 107·9 |
| „ 27.............. | 114 | 109·8 | 115·2 | 112 |
| „ 29.............. | 103 | 101·2 | 103 | 101·5 |
| Sept. 26.............. | 102·8 | 100 | 104 | 102 |
| „ 29.............. | 92·5 | 88·7 | 93·2 | 91 |
| „ 29.............. | 98·2 | 95 | 99 | 98 |
| „ 30.............. | 99·8 | 95·8 | 100·3 | 98 |
| Nov. 8.............. | 87·2 | 84·5 | 87·3 | 85·3 |
| Means .............. | 103·22 | 99·65 | 103·89 | 101·59 |

TABLE V. Comparison of Blackened-bulb Thermometer in Air-pump Receiver with ordinary Blackened-bulb Thermometer *in vacuo*.

| Date. | Mean of two b. bulbs *in vacuo*. Corrected. | B.-b. therm. in air-pump Receiver. Corrected. | Diff. |
|---|---|---|---|
| Sept. 12. | | | |
| h m | | | |
| 11 47 | 121·9 | 119 | 2·9 |
| 0 2 | 122·7 | 121 | 1·7 |
| 0 6 | 122·8 | 121·2 | 1·6 |
| 0 12 | 123·0 | 122·5 | 0·5 |
| 0 17 | 120·9 | 121·5 | −0·6 |
| 1 13 | 121·1 | 121·5 | −0·4 |
| Sept. 16. | | | |
| 10 0 | 100 | 102·5 | −2·5 |
| 10 20 | 104·5 | 107 | −2·5 |
| 10 30 | 107·8 | 110 | −2·2 |
| 10 40 | 108·8 | 111 | −2·2 |
| 10 44 | 111·2 | 112 | −0·8 |
| 10 48 | 102·5 | 105 | −2·5 |
| Means ............ | 113·9 | 114·5 | −0·6 |

The discussion on this paper will be found at p. 170.

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XVII. *On Temperature in Sun and Shade. An account of Experiments made at Harpenden, Herts.* By the Rev. FENWICK W. STOW, M.A., F.M.S.

[Received December 18, 1872. Read January 15, 1873.]

THIS paper is intended to be supplementary to that on Solar Radiation, already submitted to this Society, and is simply an account of some experiments made in September last.

The object proposed was to determine the effect of different conditions of exposure to radiation upon thermometers of different kinds. A number of instruments were most kindly placed at the author's disposal by Mr. Casella. Of these a set comprising a thermometer with a large bulb, an ordinary verified thermometer, of Mr. Casella's "Kew Observatory" pattern, and another of the same kind, but with the bulb blackened, were placed in each of three positions. One set was exposed to the full rays of the sun at 4 feet from the ground; another was placed on what might be called a zenith-stand *, that is, effectually screened from the direct rays of the sun, and from radiation from the ground, but exposed to the sky in the zenith, and to the whole northern heavens; a third was exposed to less than a quarter of the whole sky, and that only near the northern horizon, placed in fact just as on an open stand of the ordinary construction, only that the body of the stand was much deeper and a little wider than usual, and it was only roughly constructed for the special purpose. Care, however, was taken that the usual conditions of an open stand, including free exposure to currents of air, were not departed from. A set of three maximum thermometers, comprising a blackened bulb *in vacuo*

* The apex of the screen in the "zenith-stand" was 2 feet higher than the bulbs of the thermometers, which were from 1 foot to 1 foot 6 inches distant from it horizontally. The front of this stand was about 3 feet wide, the back being formed of boards leaning against it at an angle of about 45°.