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THE COMPARISON OF SUNSHINE RECORDERS OF THE CAMPBELL-STOKES TYPE

A Report prepared in the Meteorological Office, London, at the request of the INTERNATIONAL METEOROLOGICAL COMMITTEE

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THE COMPARISON OF SUNSHINE RECORDERS OF THE CAMPBELL-STOKES TYPE

A Report Prepared in the Meteorological Office, London, at the request of the International Meteorological Committee.

Introductory.—In April 1913 at the tenth meeting of the International Meteorological Committee, held in Rome, attention was called to the "inadequacy of the method hitherto employed for registering sunshine by means of the glass ball heliograph." The Committee recommended the Commission for Radiation "to initiate experiments for the comparison of the different forms of instruments of this type with each other, and especially with the English Campbell-Stokes instrument, which is already made according to a precise specification, in order that, as far as possible, uniformity in the size and composition of the glass of the sphere and also of the paper may be proposed to the makers of the instruments."

In September, 1921, at the eleventh ordinary meeting of the International Meteorological Committee, held in London, Dr. Maurer, the President of the Commission for Radiation, again raised the question of the glass sphere heliograph in connexion with his researches on a new instrument called the sunshine chronograph. Dr. Maurer has already obtained thirteen months' simultaneous records of sunshine with his chronograph and a Campbell-Stokes sunshine recorder made by Messrs. Negretti & Zambra. The results, which are set out in the Report of the Committee for 1921, show that the Negretti instrument recorded about one per cent less sunshine than the chronograph.

With a view to obtaining further information on the subject, Sir Napier Shaw, F.R.S., President of the Committee, proposed Resolution 48 of the London Meeting, which is as follows :—

> "That the British Meteorological Office be requested to compare the specification of Negretti & Zambra's instrument with the Hicks instrument used in the Meteorological Office, and with any other instruments to which they may have access, and to submit the results to the Committee with a view to a detailed specification of the instrument which Dr. Maurer has found to give so reliable a record."

In accordance with this resolution, the British Meteorological Office arranged with Dr. Maurer to send to London the Negretti sunshine recorder with which he had worked and a supply of cards, of the same kind as he had used, for use with it. This instrument has been exposed on the roof of the Observatory at Kew with the sunshine recorder belonging to the Observatory and a new Campbell-Stokes recorder made by Hicks according to the latest specification of the British Meteorological Office.

The Instruments.—The three recorders are essentially of the same design, *i.e.* a glass sphere brings the sun's light to a focus on a card mounted in a spherical metal bowl, thus charring or scorching the card whenever the sun is shining. Table I gives the important points of the specification of the Campbell-Stokes sunshine recorder as well as the points of deviation from the specification, if any, of each instrument. The full specification of the Meteorological Office standard recorder is given in Appendix I. In the subsequent discussion it will be convenient to refer to the individual recorders as A, B and C, defined as follows :—

Kew Standard, M.O. 12 - - - - - A
New instrument, M.O. 130 - - - - B
Dr. Maurer's Negretti recorder - - - C

TABLE I.—PARTICULARS OF THE INSTRUMENTS

Parts of the Instrument	M.O. Specification	Kew Standard M.O. 12 A	M.O. 130 B	Negretti (Dr. Maurer's) C
Glass Sphere—				
Support	—	Resting on the stand.	Resting on the stand.	Held between two padded caps.
Colour -	Colourless or very pale greenish tint.	Light straw colour.	Practically colourless.	Light straw colour.
Diameter -	3·95–4·05 in.	4·00 in.	4·00 in.	4·01 in.
Weight -	2·96–3·06 lbs.	3·03 lb.	3·00 lb.	2·97 lb.
Focal length	2·94–2·96 in.*	2·97 in.	2·95 in.	2·97 in.
Bowl—				
Form - -	*See* Appendix I.	One piece of metal shell rigidly fixed to the standard.	According to M.O. specification.	Cut in two by a plane through the polar axis and the two halves hinged to the semi-circular arc.‡
Lengths of Chord referred to centre line of Card—				
(*a*) Equinoctial, 6h. to 18h.	5·73 (±·01) in.	5·76 in.	5·75 in.	5·91 in.
(*b*) Summer, 6h. to 18h.	†5·54 in.	5·57 in.	5·55 in.	5·76 in.
(*c*) Winter, 6h. to 18h.	†5·54 in.	5·39 in.	5·36 in.	5·51 in.

* The figures refer to sodium light.
‡ The hinge was not made use of in the main series of observations. (*See* Addendum).
† Computed.

The Method of Experiment.—A difference in the cards is as likely a source of discrepancy in the records as a difference in the spheres or other parts of the instrument. With a view to

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making the comparison as comprehensive as possible, the British and Swiss cards* (*i.e.*, cards supplied by Dr. Maurer) were exposed in C on alternate days, whilst only British cards were exposed in the other two recorders.

The three recorders were placed side by side on the south parapet of the roof of Kew Observatory, B being in the middle. The exposure of the instruments is satisfactory, except perhaps, on a few days in July, when the late evening sunshine may be liable to interruption by trees. All the three instruments were in good adjustment as regards latitude, level and orientation. The records obtained from the three instruments were then measured by the same person according to the procedure laid down in the "Observer's Handbook," pp. 98-99, 1921 edition.

The Data.—Since it is obvious that any two Campbell-Stokes sunshine recorders will give identical records of duration of sunshine during periods of bright uninterrupted sunshine, it seemed desirable to employ a method of tabulation which would tend to bring into prominence the differences which would be likely to appear during periods of weak or intermittent sunshine. It was, therefore, decided to tabulate the following data for each card :—

Total duration of sunshine in hours and tenths

(*a*) All hours sunrise to sunset.

(*b*) Between 9h. and 15h. (period of bright sunshine).

(*c*) Before 9h. and after 15h. (period of feeble sunshine).

Although it was recognized that the two subdivisions (*b*) and (*c*) were by no means mutually exclusive, it was thought that they would serve to bring out any marked differences that might exist. The results obtained for the whole period are shown in Table II.

TABLE II.—TOTAL SUNSHINE, APRIL, 1923–MARCH, 1924.

Instrument	All hours Sunrise to Sunset		Bright Sunshine (9h–15h)		Feeble Sunshine (Remainder)	
	hours	per cent of B	hours	per cent of B	hours	per cent of B
A - - -	1362·5	96·4	844·7	96·0	517·8	97·0
B - - -	1413·6	100	879·9	100	533·7	100
C - - -	1368·2	96·7	863·8	98·2	504·4	94·5

It will be seen from Table II that the recorder B registers appreciably more sunshine than either of the other two instruments. Though there is no reason to believe that this instrument gives absolutely the maximum record, it will be

* The cards are practically of the same quality as those which were in use in the British Meteorological Office prior to the war.

convenient to take it as the standard and express the amounts recorded by the other two under various conditions as percentages of the B record. This has been done in Table II.

We see that, in the case of the instrument C, the deficiency is markedly greater for the period of feeble sunshine—when it amounts to over five per cent—than for the period of bright sunshine, when it is barely two per cent. On the average, B records fully three per cent more than C, and we should, therefore, expect it to record two per cent. more than Dr. Maurer's chronograph.

The Kew standard instrument is seen to record rather less sunshine than C during the 9h.-15h. period, but rather more during the remaining hours of daylight.* Compared with B, it records a larger percentage of feeble sunshine than of bright sunshine. This result is difficult to explain, and seems to point to some defect in A, which makes it record too little sunshine independently of the intensity.

In Table III separate consideration has been given to occasions when Swiss cards were in C. The results for the summer (1923, May-September) and winter (1923, April, October, November, December, 1924, January, February, March) are also given separately. It will be noted that in each case C recorded a rather higher percentage with British cards than with Swiss cards.

TABLE III.—COMPARISON OF THE RECORDS OF SUNSHINE (B = 100)

Cards	All Hours			9–15 Hours		
	A	B	C	A	B	C
April 1923–*March* 1924.	%	%	%	%	%	%
(*a* All cards - - -	96·4	100	96·7	96·0	100	98·2
(*b*) Swiss cards in C and British cards in A and B.	96·2	100	96·4	95·4	100	97·5
(*c*) British cards in the three instruments.	96·6	100	97·1	96·6	100	98·8
Seasonal Variation.						
Summer.						
(*a*) Swiss cards in C and British cards in A and B.	96·8	100	97·2	95·5	100	98·4
(*b*) British cards in the three instruments.	99·1	100	99·5	96·5	100	98·8
Winter.						
(*a*) Swiss cards in C and British cards in A and B.	95·4	100	95·4	95·3	100	96·6
(*b*) British cards in the three instruments.	96·2	100	97·0	96·7	100	98·8

* This difference is probably due to the effect of the bad focussing in reducing records of feeble sunshine in C.

TABLE IV.—KEW INSTRUMENT A : PERCENTAGE FREQUENCY OF DEPARTURES FROM THE READINGS OF B (B—A).

Hours	Cards	Departures from the Readings of M.O. 130 in Hours																			Number of Occasions	Period
		−0·5	−0·4	−0·3	−0·2	−0·1	Sunless	Agreement	+0·1	+0·2	+0·3	+0·4	+0·5	+0·6	+0·7	+0·8	+0·9	+1·0	+1·1	+1·2		
All hours	British	0·0	0·0	0·0	2·2	3·1	19·4	16·3	16·5	16·3	8·7	7·9	5·3	2·5	0·6	0·8	0·0	0·0	0·0	0·4	356	Apr., 1923–Mar., 1924.
9–15h. G.M.T.	British	0·0	0·0	0·3	0·3	1·7	21·8	27·0	21·3	15·4	5·3	3·4	2·0	0·3	0·6	0·3	0·0	0·0	0·3	0·0	356	do.
SEASONAL VARIATION (SUMMER AND WINTER).																						
Summer																						
All hours	British	0·0	0·0	0·0	0·7	4·0	4·7	14·0	18·7	20·0	14·0	12·6	6·0	3·2	0·7	1·4	0·0	0·0	0·0	0·0	150	1923, May, June, July, August, September.
9–15h. G.M.T.	British	0·0	0·0	0·0	0·0	0·7	8·0	33·3	22·7	19·3	9·3	3·3	2·0	0·0	1·4	0·0	0·0	0·0	0·0	0·0	150	
Winter																						
All hours	British	0·0	0·0	0·0	3·4	2·4	30·1	18·0	15·0	13·6	4·8	4·4	4·9	1·9	0·5	0·5	0·0	0·0	0·0	0·5	206	1923, Apr., Oct., Nov., Dec., 1924, Jan., Feb., Mar.
9–15h. G.M.T.	British	0·0	0·0	0·5	0·5	2·4	32·0	22·3	20·5	12·6	2·4	3·4	1·9	0·5	0·5	0·0	0·0	0·0	0·5	0·0	206	

TABLE V.—RECORDER C: PERCENTAGE FREQUENCY OF DEPARTURES FROM THE READINGS OF B (B—C).

Hours	Cards	−0·5	−0·4	−0·3	−0·2	−0·1	Sunless	Agreement	+0·1	+0·2	+0·3	+0·4	+0·5	+0·6	+0·7	+0·8	+0·9	Number of Occasions	Period
All hours	All Cards.	0·3	0·0	0·3	1·5	4·5	20·5	15·8	19·0	14·6	9·8	6·2	4·2	2·4	0·6	0·0	0·3	336	Apr., 1923–Mar., 1924.
	British	0·6	0·0	0·0	1·7	3·4	22·3	15·4	24·0	13·7	9·7	4·0	3·5	1·2	0·0	0·0	0·6	175	
	Swiss	0·0	0·0	0·6	1·2	5·6	18·6	16·1	13·7	15·5	10·0	8·8	5·0	3·7	1·2	0·0	0·0	161	
9–15h. G.M.T.	All Cards.	0·0	0·0	0·3	1·7	9·3	21·2	34·3	21·1	8·4	1·7	0·3	0·8	0·6	0·0	0·3	0·0	356	Apr., 1923–Mar., 1924.
	British	0·0	0·0	0·0	2·7	7·6	23·3	36·2	20·5	8·1	1·6	0·0	0·0	0·0	0·0	0·0	0·0	185	
	Swiss	0·0	0·0	0·6	0·6	11·1	19·3	32·2	21·6	8·8	1·7	0·6	1·7	1·2	0·0	0·6	0·0	171	
SEASONAL VARIATION (SUMMER AND WINTER).																			
Summer.																			
All hours	All Cards.	0·0	0·0	0·0	1·5	6·2	5·4	13·8	18·5	19·2	15·4	10·8	6·9	1·5	0·8	0·0	0·0	130	1923, May, June, July, August, September.
	British	0·0	0·0	0·0	1·5	3·2	4·6	13·8	26·2	13·8	18·5	7·7	9·2	1·5	0·0	0·0	0·0	65	
	Swiss	0·0	0·0	0·0	1·5	9·3	6·3	13·8	10·8	24·6	12·3	13·8	4·6	1·5	1·5	0·0	0·0	65	
9–15h. G.M.T.	All Cards.	0·0	0·0	0·0	0·0	9·3	8·0	44·0	27·3	8·7	2·0	0·0	0·7	0·0	0·0	0·0	0·0	150	1923, May, June, July, August, September.
	British	0·0	0·0	0·0	0·0	9·3	9·3	45·4	24·0	9·3	2·7	0·0	0·0	0·0	0·0	0·0	0·0	75	
	Swiss	0·0	0·0	0·0	0·0	9·3	6·7	42·7	30·7	8·0	1·3	0·0	1·3	0·0	0·0	0·0	0·0	75	
Winter.																			
All hours	All Cards.	0·5	0·0	0·5	1·5	3·4	30·1	17·0	19·4	11·6	6·3	3·4	2·4	2·9	0·5	0·0	0·5	206	1923, Apr., Oct., Nov., Dec.; 1924, Jan., Feb., Mar.
	British	0·9	0·0	0·0	1·8	3·6	32·7	16·5	22·7	13·6	4·6	1·8	0·1	0·9	0·0	0·0	0·9	110	
	Swiss	0·0	0·0	1·0	1·0	3·2	27·2	17·7	15·6	9·4	8·3	5·2	5·2	5·2	1·0	0·0	0·0	96	
9–15h. G.M.T.	All Cards.	0·0	0·0	0·5	2·9	9·2	31·1	27·2	16·5	8·2	1·4	0·5	1·0	1·0	0·0	0·5	0·0	206	1923, Apr., Oct., Nov., Dec.; 1924, Jan., Feb.,
	British	0·0	0·0	0·0	4·5	6·4	32·7	30·0	18·2	7·3	0·9	0·0	0·0	0·0	0·0	0·0	0·0	110	
	Swiss	0·0	0·0	1·0	1·0	12·5	29·2	24·0	14·6	9·4	2·1	1·0	2·1	2·1	0·0	1·0	0·0	96	

The data of Table III support the view that the loss of record with the Kew instrument is independent of the intensity of the sunshine, while with the recorder C there is a greater loss during periods of feeble sunshine.

A detailed analysis of the individual records is given in Tables IV and V, where the percentage deviations of the daily amounts recorded by the instruments A and C are tabulated on a frequency basis. Occasions of no sunshine are entered separately under the heading "sunless." It will be noticed that, although B normally registered more than either of the others, occasions were fairly frequent when the reverse occurred. It is not intended to attach much importance to these tables. They are to be regarded rather as indicating the scatter of the errors of measurement than anything else. Notes on certain occasions of large difference are, however, given below :—

1. Loss of 0·9 hr. by C with a British card on April 9 1923 at 6h. 25m. This was most probably due to the defective shape of the bowl and the yellow colour of the sphere.

2. Loss of 1·2 hr. by A with a British card on Oct. 8 1923 between 12h. 30m. and 14h. 30m. The sunshine was feeble. The card in A was of a lighter shade than those in B and C.

3. Excess of 0·3 hr. by A with a British card on Dec. 9 1923. The record from A begins at 10h. 10m. whereas the record from B begins at 10h. 25m. (although the card from A is of a pale colour). There is no apparent reason for the discrepancy.

4. Excess of 0·5 hr. by C with a British card. The C record begins at 8h. 40m., the A record at 9h. 3m. and the B record at 9h. 18m. Probably the card in C was shifted from its correct position.

5. Excess of 0·3 hr. by C with a Swiss card. The trace on the Swiss card begins 8h. 30m. The trace from B on the British card starts at 8h. 47m. The Swiss card is of deeper blue colour than the British card in B.

General Conclusions.—The following general conclusions are reached :—

(*a*) The instrument C formerly in use by Dr. Maurer records up to 5 per cent less sunshine than a standard instrument B, the deficiency depending to some extent on the intensity of the sunshine.

(*b*) The A recorder registers, on the average, about the same total amount of sunshine as the recorder C but the influence of the intensity of the sunshine is not strongly marked.

Sources of Error.—Examination of Table I shows that the recorder B is in good agreement with the specification in all

respects. In the other recorders, there are two marked points of divergence from the specification :—

(*a*) Both spheres are of a "light-straw colour."

(*b*) The diameter of the bowl of the recorder C is markedly in excess of the specified value (5·73 inches).

It remains to be seen whether these points of difference are sufficient to produce a marked effect on the records.

Previous investigations carried out in the Meteorological Office have shown clearly that the colour of the sphere is of considerable importance. As an example, the result of a comparison between a new sphere and a discoloured sphere carried out at Kew Observatory in 1902* may be quoted. In this case the discoloured sphere was found to record 17 per cent less sunshine than the clear sphere. It is evident, therefore, that the discolouration of the two spheres now under notice is probably sufficient to explain the whole of the—comparatively small—deficiencies that have been found.

Apart from the colour, two other points call for consideration, (*a*) the focal length and (*b*) the optical qualities of the spheres as regards uniformity and freedom from striæ. The focal lengths are given in Table I for axial pencils of sodium D light. Both the A and C spheres gave values slightly above that specified for M.O. recorders, but investigation has shown that the effects on the records are probably inappreciable. All three spheres showed a lack of optical uniformity, there being little to choose between them in this respect.‡ When the records obtained with B were subsequently compared with those from a sphere unusually free from striæ, however, it was found that no effects from this cause could be detected.

There remains the question of the dimensions of the bowls. It will be seen from the figures given in Table I that the bowl of C is larger than either of the others, and it has been computed that its radius is 2·96 inches or about 0·1 inch more than the specified value. The effect of this would depend to a considerable extent on the centring of the sphere.† Assuming that it is exactly concentric with the bowl, the burn would be badly focussed near the times of the change over from winter to equinoctial and from equinoctial to summer cards, resulting in a diminished record. On the other hand, the increased radius of the bowl would result in an apparent increase (of 3% approximately) in the measured duration of sunshine on cards graduated for the standard radius. It is difficult to say without very prolonged investigation to what extent these opposing effects would neutralize each other.

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* *Annual Report of the Meteorological Committee*, 1902, p. 106.

‡ The method used for determining the focal length and for investigating the optical homogeneity of the spheres was described in the *Meteorological Magazine*, Feb. 1926, pp. 1–5.

† *See* Appendix II.

In conclusion, it is worthy of remark that the comparison of the three recorders has led to the result that the maximum duration of sunshine is registered by the recorder in closest agreement with the Meteorological Office specification. The comparison previously made between the Negretti instrument and Dr. Maurer's chronograph, together with the data now presented, lead finally to the conclusion that a standard Meteorological Office recorder running side by side with Dr. Maurer's instrument would, on the average, register slightly more sunshine than the latter.

ADDENDUM

(Added May 25th, 1926)

Throughout the tests described in the preceding Report, the standard procedure adopted in the British Isles for exposing sunshine cards was adopted in all three recorders. That is to say, the cards were changed after sunset, and no attempt was made to increase the duration of the burn by trimming the cards or otherwise. The special construction of the recorder C, however, permits of one-half of the slotted bowl being hinged back while the solar image falls within the other half of the bowl. Provided, therefore, that the card is exposed in two halves, changed at midday, the full aperture of the sphere may be employed throughout the daylight period, the obscuration due to the horns being thus avoided. Near sunset and sunrise, we may expect the effect to be quite appreciable.

In order to complete the investigation, therefore, it was decided to compare the recorder C with the Kew standard instrument A for a short period, making use of the special feature of C. The results for February, March and April, 1926 are shown in Table VI.

These results are indicative of a beneficial effect due to the special construction of the recorder C during periods when the sun is at a low altitude. It is curious, however, that this improvement is only shown in a marked degree during the month of March. During April, indeed, the Kew instrument actually registered two per cent more sunshine during the "feeble sunshine" period than C. It should be remembered, however, that the effect of the hinged bowl diminishes rapidly as the sun increases in altitude. If the sun did not emerge from mist or cloud until it was twenty degrees or more above the horizon, it would make little difference whether the horn were in the way or not. Also, the figures in Table II show that a correction of about $2\frac{1}{2}$ per cent. must be added to the "feeble sunshine" records from C before the effect of the hinged bowl can be estimated.

From Table VI, we may deduce the result that when the hinged bowl is in regular use C will register about 0 · 7 per cent.

more sunshine than the Kew standard instrument. The corresponding figure without using the hinged bowl, is 0 · 3 per cent (Table II). This difference is very small, and the general conclusions reached in the report are, therefore, not appreciably affected.

TABLE VI.—COMPARISON OF KEW RECORDER A AND RECORDER C USING HINGED BOWL.

Month 1926	All hours Sunrise to Sunset		Bright sunshine 9h–15h		Feeble sunshine (Remainder)	
	A	C	A	C	A	C
February -	46·1	46·2	34·8	34·8	11·3	11·4
March - -	90·3	91·9	62·0	62·1	28·3	29·8
April - -	111·0	111·0	65·2	66·0	45·8	45·0
Total -	247·4	249·1	162·0	162·9	85·4	86·2

APPENDIX I

SPECIFICATION OF SUNSHINE RECORDER

(Standard Dimensions of Campbell-Stokes Sunshine Recorders)

For the purpose of testing the bowl specially graduated strips of brass, equivalent to the three patterns of cards used in the recorder, and each 0·02 inch thick, will be used.

The width of the equinoctial card is to be 1·56 inches, and of the summer and winter cards 1·26 inches.

The radius of the central arc of the summer and winter cards is to be 10·05 inches.

A time scale in which 12 hours are represented by 9·00 inches, and also a central line parallel to its edges, are to be engraved upon the strip representing the equinoctial card. Central lines only are required upon the curved cards. In placing the metal strips for measurement in case there is any "play," the position for measurement will be when the lower edge is pressed down to the bottom of its groove.

THE BOWL

1. The diameter of the bowl, measured between the centres of the 6 o'clock marks on the metal equinoctial card when in its place, is to be 5·73 inches (± 0·01 inch).

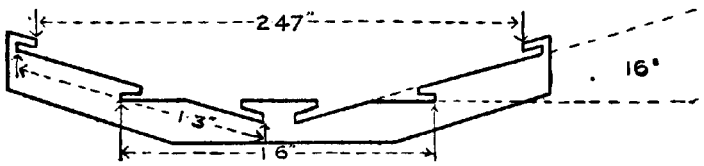
2. The middle line of the equinoctial card when in its place must lie equidistant from the top and bottom flanges of the bowl.

3. The distance between the exposure edges of the upper winter flange and the lower summer flange must not be less than 2·45 inches, nor exceed 2·50 inches.

4. The distances from the middle line on the equinoctial card to the middle lines on the summer and winter cards are to be 0·70 inch (± 0·02 inch).

5. The inclination of the summer card, in place, to the winter card, in place, is to be 32° ± ½°, symmetrically arranged with regard to the equinoctial card.

6. The section of the supporting surface by a plane through the polar axis is to be as represented in the accompanying drawing :—



THE SPHERE.*

1. *Material*—The sphere to be of uniform and well annealed glass, whose refractive index for Sodium D light is about 1·512. (*See* paragraph 5.)

2. *Colour*—The glass to be colourless or of a very pale yellowish green tint.

3. *Focal Length*—This is defined as the distance from the centre of the sphere of the optical focus for a narrow axial pencil of parallel Sodium D light. The focal length determined from the mean of measurements along any 4 arbitrarily selected axes to be 2·95 ± ·01 inches. The focal length determined from measurements along any arbitrarily selected individual axis must not lie outside the range 2·93–2·97 inches.

4. *Homogeneity*—No optical irregularity in the glass must extend over the whole cross-section of any cylinder of one inch diameter, whose axis passes through the centre of the sphere. Optical irregularity is defined as an imperfection which prevents the formation of a sharp image with narrow pencils of parallel rays of sodium light.

5. *Size*—The diameter of a sphere for which the refractive index for Sodium D light is 1·512 and focal length 2·95 inches, is 4·00 inches. Small variations of diameter not exceeding ± ·05 inch are, however, permissible, subject to condition 3 being satisfied.

MOUNTING OF THE BOWL AND SPHERE

1. In view of the use of recorders in different latitudes, it is an advantage that the bowl should be so mounted as to be capable of being adjusted for latitude without moving the base.

2. The "belt" from which the bowl is made should be so cut that when the bowl is adjusted for its mean latitude the plane of the cut shall be approximately horizontal.

3. The mounting of the sphere must be such as will permit of its centre being readily adjusted to the centre of the bowl.

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* Revised, May 29, 1926.

APPENDIX II

ERROR DUE TO SIZE OF BOWL†

The method adopted for testing the bowl of a sunshine recorder in order to ascertain whether it has been made to standard dimensions is to insert a brass template 0·02 inch thick in the equinoctial grooves. The brass template is graduated with hour lines 0·75 inch apart and the test consists in determining the distance (d) apart of the points of intersection of the 6h. and 18h. lines with the central line. The standard value of d is, clearly,

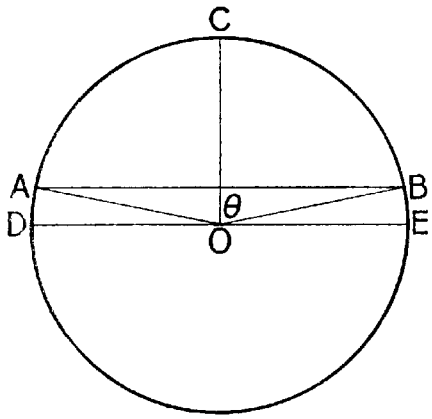
$$\frac{12 \times 0{\cdot}75 \times 2}{\pi} = 5{\cdot}73 \text{ inches}$$

We have now to determine the effect on the record of variations of d from the standard value. It will be assumed that the sphere and bowl are concentric and that any effects due to bad focussing are negligible. This will be true so long as variations in d are small.

Let O be the common centre of sphere and bowl, C the noon mark, A the 6h. and B the 18h. mark on the template. Then

$$AB = d$$

and the arc ACB $= 12 \times 0{\cdot}75'' = 9$ inches.



Let 2θ be the angle subtended by the chord AB at the centre and let D be the diameter DE of the bowl. Then

$$d = D \sin \theta \quad \text{..... (i)}$$

and the arc ACB $= D\theta$ or $\theta = \frac{9''}{D}$ ..... (ii)

In 12 hours the solar image would sweep out the semi-circle DCE, the length of which is $D \times \frac{\pi}{2}$. This would give an apparent duration of $\frac{D}{0{\cdot}75} \times \frac{\pi}{2}$ hours on standard cards. One hour of sunshine would be recorded, therefore, as $\frac{D}{0{\cdot}75} \times \frac{\pi}{2} \times \frac{1}{12}$ hours or $\frac{D}{5{\cdot}73}$ hours. In other words the apparent duration is to the real duration as D is to the standard diameter, 5·73 inches.

† For a discussion of other errors to which the Campbell-Stokes sunshine recorder is liable see *The Dictionary of Applied Physics*, Vol. III, 1923, pp. 511–2.

D is not, however, obtained directly from the measurement, the length actually measured being the chord AB. It is clear, however, that no appreciable error will be made by assuming that AB $= D$, unless θ differs very materially from $\frac{\pi}{2}$. Thus, suppose $D = 6{\cdot}0$ inches (representing an error of more than a quarter of an inch in the diameter) θ would clearly be equal to $1{\cdot}5$ radian or $85° 57'$. The corresponding value of d, from (i), is $5{\cdot}985$ inches, a quantity which differs from D by an amount scarcely greater than the probable error of measurement. For practical purposes, therefore, it may be assumed that a measurement between the 6h. and 18h. lines on the template gives the diameter of the bowl, and the records may be corrected for any error in diameter by the rule given above, provided always that the sphere and bowl are concentric.

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