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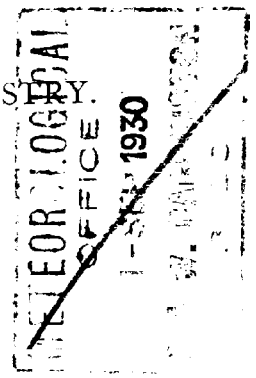

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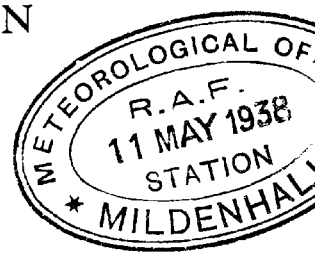

By E. G. BILHAM, B.Sc., D.I.C., and
J. E. BELASCO, B.Sc.

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THE EFFECT OF VARIATION IN RELATIVE WIND FORCE ON THE READINGS OF THE WET AND DRY BULB THERMOMETERS IN A PORTABLE SCREEN ON BOARD SHIP

By E. G. BILHAM, B.Sc., A.R.C.S., D.I.C., and
J. E. BELASCO, B.Sc.

Introduction.—The measurement of the temperature and humidity of the air at sea involves problems different from those arising on land. If a Stevenson screen could be suspended 4 feet above the open sea, the readings of dry and wet bulb thermometers placed in the screen could be regarded in the same light as those obtained in a screen placed at a height of 4 feet above open grass land. We could assume that the readings gave a sufficiently close approximation to the true conditions at that level for ordinary meteorological purposes. The main source of error would be the warming up of the screen as a whole by direct sunshine. This error would tend to increase as the wind velocity, (and, therefore, the ventilation of the screen) decreased. In ordinary practice, however, these ideal conditions cannot be realised. The screen must be carried in a ship, a complication which immediately introduces new factors. In the first place, any attempt to adhere to a fixed height above sea level, such as 4 feet, must be abandoned, owing to the wide variations in the sizes of ships. Secondly, a ship is a large mass of metal and timber, usually carrying powerful internal sources of heat. The ship's structure will ordinarily have different coefficients of absorption and reflection for radiation from those of sea water. We may, therefore, expect the air to be heated appreciably in passing over the ship. It is clear, then, that the measurement of temperature and humidity on board ship resolves itself into the problem of making the best of what is, essentially, a bad site for meteorological work.

It is obvious that the thermometer screen should be placed in such a position that the air will reach it direct from the sea, before its temperature has been changed by contact with the ship. This is by no means easy to arrange; it is in fact impracticable on large ships to secure on all occasions complete freedom from contact with the ship, and consequent temperature effects, at any place on the deck of the ship. This desideratum, however, makes it imperative to use a portable type of screen.

In considering the errors likely to be present in observations taken at sea in portable screens, we have to discriminate between those inherent even in the best windward exposure and those introduced by the screen itself. The latter arise, as has already been mentioned, mainly from the heating of the screen by sunshine. The selection of a site on the windward side of the ship ensures the maximum rate of flow of air through the screen and, therefore, tends to minimise such errors. Finally then, we may assert that observations taken with thermometers in

a portable screen placed as far as possible to windward represent the best that can be done so long as we adhere to thermometers without artificial means of ventilation.

With the above considerations in mind, the Meteorological Office has, in recent years, adopted the policy of gradual replacement of fixed shipboard screens by portable screens in observing ships of the Merchant Navy. Not much was known, however, about the errors due to this type of screen under sea-going conditions and it was decided, therefore, to investigate the matter in collaboration with the Admiralty. An accuracy of the order of one degree Fahrenheit was aimed at in measuring wet and dry bulb temperatures under the best conditions of exposure possible at sea, and the object of the investigation was to ascertain whether this accuracy was normally obtainable. The results of the inquiry are given in the present paper.

Method of Observation and Instruments used.—The Assmann psychrometer was chosen as the standard of reference against which the readings in the screen were to be compared. In this instrument the air is drawn past the dry and wet bulb thermometers at a constant speed by means of an aspirating fan driven by clockwork. The effect of external radiation is guarded against by protecting each bulb by two highly polished co-axial tubes. The "modified" shipboard screen is shown in Fig. I. It is a single-louvred screen of internal dimensions 7 inches long, 4 inches wide and $15\frac{1}{4}$ inches high. It has a double watershed-shaped roof to which is attached a brass plate and eye for hanging the screen. The thermometers used were those known as Mark I thermometers, graduated for every degree from $-15°$F. to $+ 115°$F., the graduations being on the stem of the thermometer and sufficiently wide apart to permit of readings being estimated to $0 \cdot 1°$F. The same precision was possible with the Assmann thermometers. As seen in the photograph, the thermometers used in the screen are first placed in wooden protectors, each consisting of a mahogany frame into which the thermometer is fitted after unscrewing a metal plate at the top. An open metal guard protects the bulb. The protectors containing the thermometers are then hung in the screen, the wet bulb being to the right and the dry bulb to the left. On the floor of the screen is a receptacle for the water bottle for the wet bulb thermometer. All the thermometers used in this investigation were tested at the National Physical Laboratory and were provided with certificates so that corrections at different points on their scales could be applied.

With the approval of the Hydrographer of the Navy observations were carried out on board H.M. Surveying Ships *Flinders*, *Beaufort*, *Kellett* and *Fitzroy*. Detailed instructions relating to the care and manner of using the instruments, their method of exposure and the taking of the observations were supplied to each ship. These are given in full as an appendix to this paper.

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Observations were taken usually twice a day, in the morning and afternoon, or at night, for a period of two months. These observations were (*a*) relative wind force, (*b*) readings of the dry and wet bulb thermometers in the portable screen estimated to 0·1°F., and (*c*) readings of the wet and dry bulb thermometers of the Assmann psychrometer also estimated to 0·1°F. From the dry and wet bulb readings, the relative humidities given by the screen and Assmann psychrometer were obtained from the appropriate tables.

Discussion of the Observations.—*A. Temperature.*—Table I below shows the mean differences (Assmann–screen) of the dry bulb readings for each ship classified according to the *relative* wind force (Beaufort scale). The number of observations is shown in brackets ( ) and where results are dependent upon fewer than five observations, these are bracketed thus [ ].

TABLE I.—DRY BULB IN °F. MEAN DIFFERENCES (ASSMANN MINUS SCREEN).

Ship.	Relative Wind Force (Beaufort Scale).								
	0	1	2	3	4	5	6	7	8
Kellett ..	[−1·8]	−·51	−·39	−·50	−·33	−·34	−·36	—	—
	(2)	(15)	(25)	(26)	(28)	(17)	(7)	—	—
Beaufort	−1·32	−·82	−1·00	−·59	−·32	[−·7]	—	[−·5]	[+·3]
	(9)	(21)	(22)	(24)	(5)	(1)	—	(1)	(1)
Fitzroy ..	+·25	+·32	+·30	+·27	+·34	[+·40]	[+·7]	[+·3]	—
	(23)	(46)	(51)	(14)	(8)	(3)	(1)	(2)	—
Flinders	−1·04	−·09	−·39	+·05	+·37	−·12	−·08	[+·7]	—
	(11)	(76)	(55)	(17)	(6)	(6)	(5)	(1)	—
Weighted means.	−·47	−·11	−·28	−·26	−·13	−·22	−·17	[+·20]	[+·3]
	(45)	(158)	(153)	(81)	(47)	(27)	(13)	(4)	(1)

These results indicate that there is no very close dependence of the temperature of the air in the screen on the relative wind force. Except in the case of the *Fitzroy*, the temperature in the screen is generally higher than that given by the Assmann, though the differences are, for the most part, small. On the whole, there is good agreement between Assmann and screen readings. The weighted mean shows that in a calm the error amounts on the average to 0·5° F., but this is within the limit aimed at, though if the rather anomalous results from *Fitzroy* are excluded the errors in a relative calm are in all cases rather greater than 1° F. In Table II an attempt has been made to estimate the frequency of errors, within given limits, that would result from the use of the " modified " portable screen in obtaining the temperature of the air. The differences (Assmann–screen) are grouped independently of the relative wind force, the mean temperature difference in each group having the value shown in the top line. Thus the values entered under " 0 " represent

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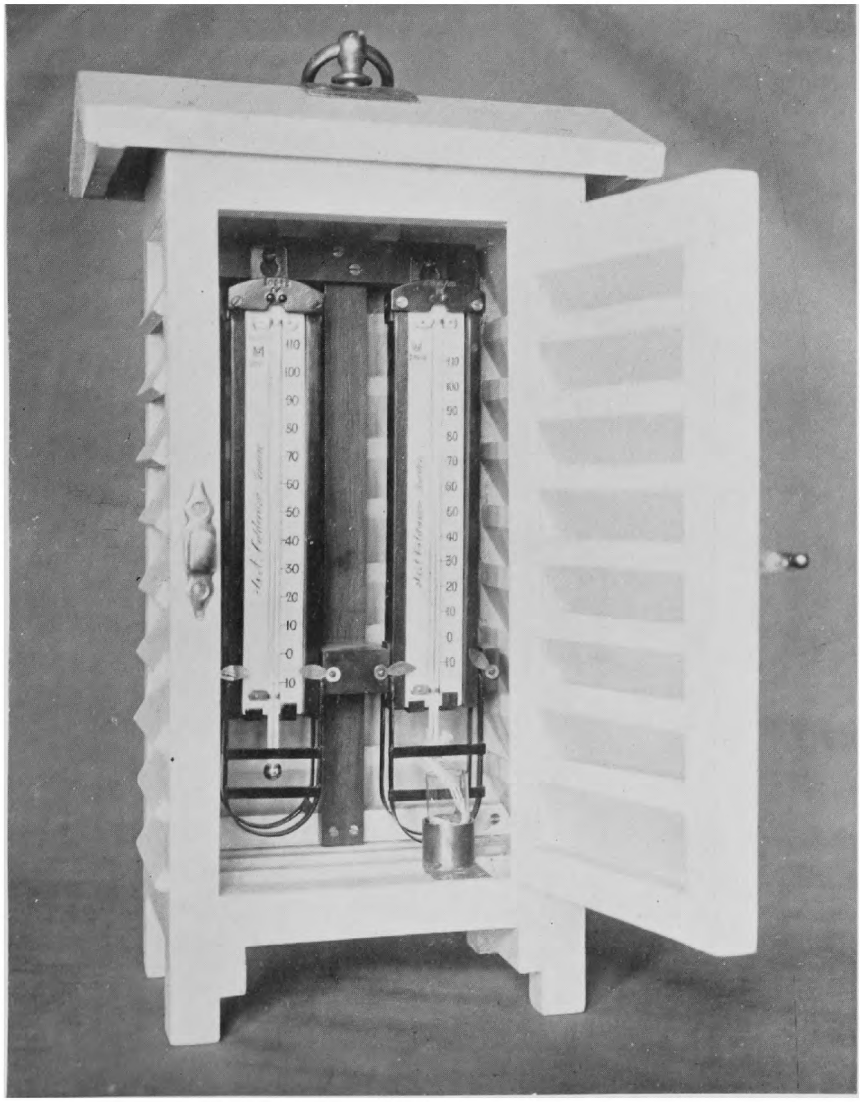

FIG. 1.—"Modified" shipboard screen with thermometers mounted in protectors.

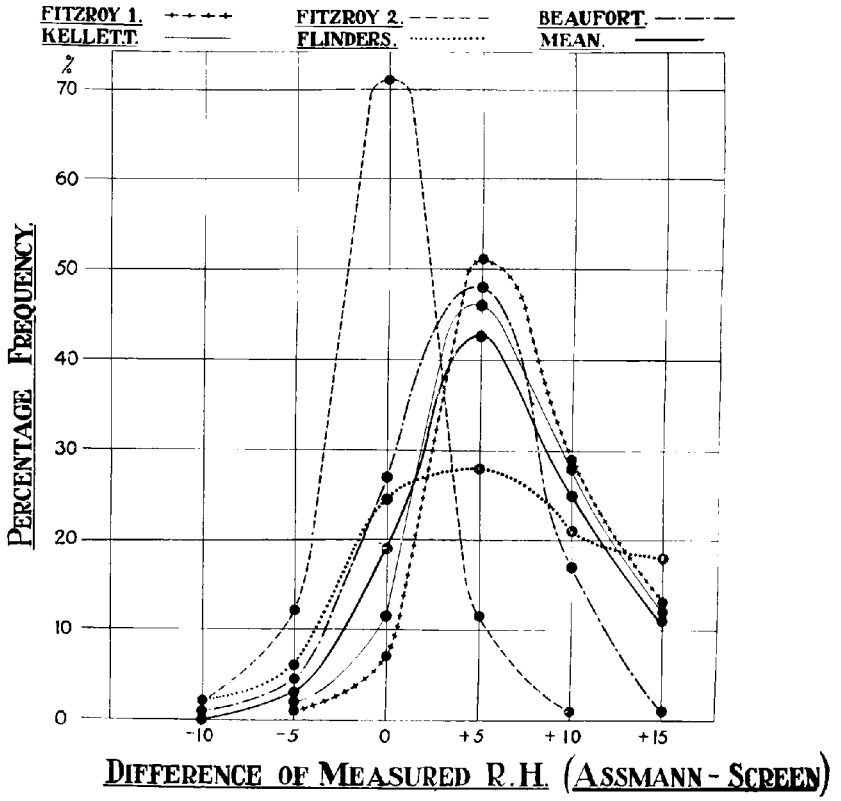

FIG. 2.—Frequency curves of the differences in the measured humidities (Assmann–screen).

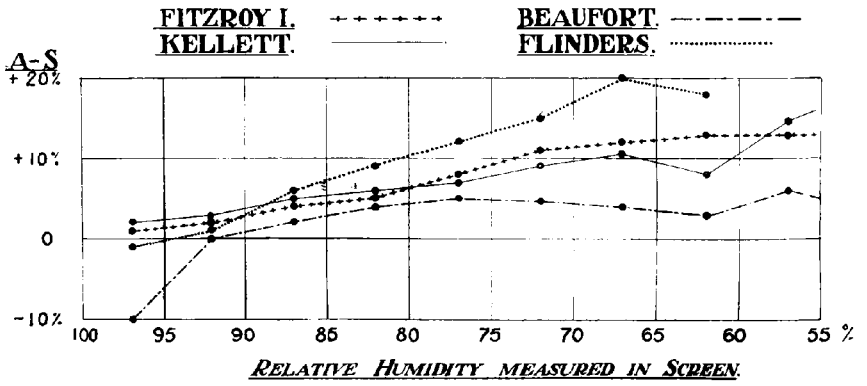

FIG. 3.—Mean differences (Assmann humidity minus screen humidity) plotted against screen humidity.

occasions when the difference was between 0·4 and −0·5°F., those under " + 1," the occasions when the difference was between 0·5 and 1·5°F., and so on.

TABLE II.—DISTRIBUTION OF DIFFERENCES (ASSMANN MINUS SCREEN).

Difference in ° F.	>−2.	−2.	−1.	0	+1.	+2.	>+2.
Ship.							
Kellett	1	5	46	62	1	1	2
Beaufort	8	4	28	28	4	—	—
Fitzroy	—	—	1	77	31	—	—
Flinders	2	7	37	68	21	—	1
Total frequencies ..	11	16	112	235	57	1	3
Percentage frequencies	2·5	3·7	25·7	54·0	13·1	0·2	0·7
			92·8				

From the above table it will be seen that in 92·8 per cent of all the observations, the discrepancy between Assmann and screen temperatures was (to the nearest whole degree) one degree or less. The difference exceeds two degrees in only three per cent of the observations.

B. Relative humidity.—The wet-bulb temperatures show, on the whole, much greater discordance than the dry bulb. To some extent, the differences are due to the fact that the Assmann is an aspirated instrument involving a different psychrometric formula from that used with the ordinary psychrometer. Relative humidities were, therefore, computed independently for each pair of observations. The first result obtained was that the screen humidities were nearly always lower than those given by the Assmann. These results are summarised in the form of frequency curves (*see* Fig. 2). The curves were drawn in the following manner: the relative humidities were computed to the nearest whole number and the differences were then obtained by subtraction. Direct plotting of the frequency of occurrence of each individual difference would have given a very irregular and confused curve. The values lying between fixed limits were therefore grouped together about the mean differences 0, + 5, + 10 - - - , − 5, − 10 - - - , and the number of observations falling into each group was expressed as a percentage of the total number of observations. The point on each curve shown above " 0 " on the difference scale actually represents the percentage of observations in which the actual difference lay between − 2 and + 2; the point above " + 5 " on the scale represents the percentage of observations in which the actual difference lay between + 3 and + 7, and so on. The significance of the curve marked " *Fitzroy* 2 " will be explained

later. *Flinders* shows some departure from the other ships, but the other curves, (*Fitzroy*, *Beaufort*, and *Kellett*) are very similar, the maximum frequency being obtained for differences lying between + 3 and + 7 per cent. In the *Fitzroy*, *Kellett*, and *Beaufort* about 50 per cent of all the observations are comprised within this range.

It was seen that the difference, Assmann humidity minus screen humidity, tended to increase with the depression of the wet bulb and accordingly curves were drawn by plotting the mean differences (Assmann minus screen) for intervals of humidity of 5 per cent against screen humidity as abscissæ (*see* Fig. 3). In the case of the *Beaufort* the curve lies mainly below the 5 per cent ordinate, thus indicating on the whole, a reasonable agreement between the Assmann and screen humidities throughout the range 55–94 per cent. There are, however, large departures for low values of humidity in the case of the other ships.

On account of the discordant observations of relative humidity, doubts arose as to the accuracy of the Assmann readings. Although the officers who made the readings undoubtedly took great care, it has to be remembered that some experience is necessary in using an instrument so unfamiliar as an Assmann psychrometer. It is possible that there might have been insufficient wetting of the tubular muslin surrounding the bulb. Again, insufficient time might have elapsed for allowing the thermometers to become steady before reading. In consequence, a further series of observations were made in the *Fitzroy* for a period of two months, the attention of the observers being specially drawn to the method of obtaining readings from the Assmann psychrometer. These observations were analysed in a similar manner to the previous ones. Table III shows the mean differences (Assmann–screen) of the air temperature classified according to the relative wind force, and Table IV the frequency distribution of the differences considered independently of the wind force. The results again show a tendency, contrary to expectation, for the screen temperature to be lower than the Assmann. The differences are, however, very small, exceeding 1 °F. in only 2·7 per cent of the readings.

TABLE III.—DRY BULB °F. (ASSMANN MINUS SCREEN).
(*Fitzroy* Second Series).

Ship.	Relative Wind Force (Beaufort Scale).									
	0	1	2	3	4	5	6	7	8	9
Fitzroy	−0·09 (8)	+·05 (9)	+·15 (19)	+·20 (13)	+·00 (15)	[+·20] (4)	[+·50] (2)	[+·35] (2)	— —	— —

TABLE IV.—DISTRIBUTION OF DIFFERENCES (ASSMANN MINUS SCREEN).
(*Fitzroy* Second Series).

Mean difference (A–S) in ° F.	>−2	−2	−1	0	+1	+2	>+2
Fitzroy frequency ..	0	0	10	55	8	2	0
Percentage frequency	0	0	13·3	73·3	10·7	2·7	0
			97·3				

As before, the relative humidities were worked out for each pair of observations of dry and wet bulb using the appropriate tables. The results show remarkable agreement, the screen humidities being only slightly lower than those given by the Assmann. These results are summarised in the form of a frequency curve in Fig. 2 (curve marked *Fitzroy* 2). The maximum frequency is obtained for differences lying between − 2 and + 2 per cent and 72 per cent of all the observations are found to be within this range. The difference exceeds 5 per cent in only 5 per cent of the observations. It was considered justifiable to accept this series as a satisfactory basis on which to form conclusions as to the accuracy of the screen observations.

Table V is derived from Tables I and III, and gives the weighted mean differences (Assmann–screen) of the air temperature classified according to the force of the relative wind.

TABLE V.—DRY BULB IN °F. (ASSMANN MINUS SCREEN).

	Relative Wind Force (Beaufort Scale).									
	0	1	2	3	4	5	6	7	8	9
Weighted means.	−·41	−·10	·23	−·20	−·10	−·17	−·08	+·25	[+·30]	—
Number	(53)	(167)	(172)	(94)	(62)	(31)	(15)	(6)	(1)	—

The inclusion of the additional observations from *Fitzroy* has not affected the deductions appended to Table I.

Table VI is derived from Tables II and IV and gives an estimate of the percentage frequency of errors within given limits resulting from the use of the " modified " portable screen.

TABLE VI.—DISTRIBUTION OF DIFFERENCES (ASSMANN MINUS SCREEN).

Difference in ° F.	>−2	−2	−1	0	+1	+2	>+2
Total frequencies ..	11	16	122	290	65	3	3
Percentage frequencies	2·1	3·1	23·9	56·9	12·8	0·6	0·6
			93·6				

We see from this table that in 93·6 per cent of all the observations the difference between the Assmann and screen temperatures was one degree or less.

Conclusion.—The analysis of the observations made on the survey ships leads to the following results :—

(1) Observations of air temperature taken from a Mark I thermometer in a " modified " marine screen will, when expressed to the nearest degree Fahrenheit, agree to within 1 °F. with those taken from an Assmann psychrometer, on more than 90 per cent of the occasions, provided the readings are taken on the windward side of the ship.

(2) With similar precautions, the relative humidity determined from dry and wet bulb readings in a " modified " screen will be within 5 per cent of the true value on 95 per cent of occasions.

(3) Large discrepancies between screen and Assmann readings are not conspicuously associated with light winds. The results do not justify a recommendation to ignore readings taken in relative winds below force 3.

APPENDIX

Instructions for Comparative Observations with Portable Screens and Assmann Psychrometers.

1. **Purpose of the Observations.**—The observations are required for the purpose of ascertaining how the readings of temperature and humidity obtained from thermometers in a portable screen are affected by variations in the strength of the relative wind over the ship. The Assmann psychrometer is specially designed for accurate measurements under all conditions, and its indications are taken as the standard values.

2. **Exposure of Instruments.**—All observations should be taken on the windward side of the ship, well away from heated objects likely to influence the results. The portable screen should be slung by its ring at a height of about five feet, the door being on the north side. The Assmann instrument is provided with a clamp having a screwed end intended to be inserted horizontally in a wooden post so that the bulbs are at a height of four or five feet. This height should be adhered to as far as possible, but on board ship it will probably be found more convenient to suspend it by means of a loop of string through the hole in the knob at the top.

3. **Observations Required.**—A set of observations includes the following :

(*a*) Weather and relative wind force at the time. Beaufort notation should be used.

(*b*) Wet and dry bulb readings of thermometers in screen, estimated to 0·1° F.

(*c*) Wet and dry bulb readings of Assmann psychrometer, estimated to 0·1° F.

A specially ruled note-book is provided. Observations should be taken twice a day for two months.

4. **Care of Wet Bulbs.**—To ensure that the results will be as reliable as possible, it is necessary to use only clean pure water for the wet bulbs. Distilled water or rain water should be used if possible. The muslin and wick should be changed once a fortnight.

To change the muslin and wick on the screen wet bulb, take the right hand thermometer, in its protector, out of the screen and turn it face downward. Cut a piece of muslin about 1½ inches square, soak it in water, wrap it tightly over the bulb, secure with three strands of wick in a clove hitch and trim with scissors. When replacing the thermometer in the screen see that the wick does not sag between the water vessel and the bulb, otherwise water will tend to drip away.

The method of changing the muslin on the Assmann wet bulb is explained below.

5. **The Assmann Psychrometer.**—In this instrument air is drawn past the bulbs of the two thermometers by means of a fan driven by clockwork, which should be fully wound before an observation.

The wet bulb (right hand) is covered with a short length of tubular wick slipped over the bulb, and before taking an observation it should be moistened as follows :—

> In the box will be found an " injector " consisting of a rubber ball with a short glass tube and a clip for closing the rubber tube above the ball when required. Release the clip and fill the ball with water after the manner of a fountain-pen filler. Hold the ball downwards, press the ball till the water rises to the top of the glass tube then clip the rubber tube to retain the water in this position. Holding the psychrometer upright push the glass tube right up the right hand inlet as far as it will go. This will ensure that the

muslin is completely wetted. Remove the injector and empty it. It is important not to squirt the water up round the thermometer bulb as splashings of water may adhere to the top of the bulb and the walls of the tube and adversely affect the accuracy of the observations.

The operation of wetting the muslin should be carried out strictly in accordance with the instructions given above.

To take an observation :—

(*a*) Moisten the wet bulb.
(*b*) Wind the clock.
(*c*) Wait for two minutes.
(*d*) Watch the wet bulb for a minute to ensure that it has become steady.
(*e*) Read the wet bulb to 0·1° F.
(*f*) Read the dry bulb to 0·1° F.

Owing to its construction, the Assmann psychrometer gives reliable readings even in full sunshine. The instrument should be kept clean and bright by polishing with chamois leather and should never be put away wet. When not in use it should be kept in its case.

To change the muslin.—Unscrew the sheath which covers the right-hand thermometer bulb. Slip off the old muslin and push one of the spare muslin tubes over the bulb. Screw the sheath on again, making sure that the inner sheath is in its right position.

To oil the clockwork.—Unscrew the dome at the top of the instrument so as to expose the clockwork. Touch the bearings with a drop of clock oil. This should be done whenever the clockwork shows signs of needing it.

In windy weather.—A hinged metal screen is provided to place over the outlets below the dome in windy weather. It should be used on the windward side of the instrument.

NOTE.—The observer should note on the first page of the book supplied the numbers of the thermometers used as wet bulb thermometers. The number will be found on the porcelain scale or on the glass stem of each thermometer.

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