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Negative depressions of the Wet-bulb.

By E.G. BILHAM.

The British system of hygrometry postulates that when the temperature is below freezing point the wet-bulb thermometer should be coated with ice, not super-cooled water. It is well known that under these conditions the reading of the wet-bulb may exceed that of the dry-bulb. The explanation of this anomaly lies in the fact that super-cooled water droplets may exist at temperatures below freezing point, and the atmospheric vapour pressure may then exceed that corresponding to saturation ice. It is not immediately obvious that a negative depression of the wet-bulb must occur in these circumstances but the result follows very simply from a study of the fundamental psychrometric formula. The same analysis provides the means of determining the maximum possible negative depression of the wet-bulb.

The psychrometric formula used in the Meteorological Office when the temperature is below freezing point is

$$e = E_i - A(t - t') \quad (1)$$
 where e is vapour pressure, E_i is the saturation pressure over ice at the wet-bulb temperature t' , t is the dry bulb temperature and A is a constant. For small values of $t - t'$, equation (1) may be written in the form

$$e = E_i - \frac{dE_i}{dt} \delta t + A \delta t$$

$$\text{or } e - E_i = -\delta t \left(\frac{dE_i}{dt} + A \right)$$

where $\delta t = t - t'$ and E_i is the saturation pressure over ice at temperature t . (2)

Since both $\frac{dE_i}{dt}$ and A are positive, it is clear that δt must be negative if e exceeds E_i , that is to say if the actual vapour pressure exceeds that corresponding to saturation over ice at the air temperature.

The highest possible value of e is E_w , the saturation pressure with respect to water at temperature t . Substituting in (2) and rearranging we see that the maximum possible value of $-\delta t$ at any temperature is given by

$$-\delta t = (E_w - E_i) / \left(\frac{dE_i}{dt} + A \right) \quad (3)$$

For vapour pressure in millibars and temperatures in degrees Fahrenheit the value A is 0.400. The values of the other quantities on the

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BY E. C. SUTHERLAND

The right hand side of equation (3) are readily obtained from tables. The computed values of $-6t$ for different temperatures are as follows:—

Temperature $^{\circ}\text{F}.$ 5° 10° 15° 20° 25° 30°

Max. negative depression of wet-bulb $^{\circ}\text{F}.$ 5.54° 5.4° 5.0° 4.0° 2.7° 0.7°

Relative humidity 116 112 109 107 104 101

Thus negative depressions up to about half of a degree Fahrenheit may occur at low temperatures.

The relative humidity at temperatures below freezing point is defined, as from 1st January 1939, as the percentage of saturation with respect to ice. It follows that under the conditions which produce negative depressions of the wet-bulb the relative humidity exceeds 100 per cent. The maximum value at any temperature is clearly equal to $100 \times E_w/E_i$. The computed values have been inserted in the table above.

The temperature at which condensation on solid objects begins when moist air is cooled below freezing point is that temperature for which the saturation pressure over ice is equal to the actual vapour pressure; this is known as the hoar frost point. In the case of air with the maximum possible degree of supersaturation the actual vapour pressure is E_w and the hoar-frost point is the temperature t for which $E_w = E_i$. The values for the temperatures already considered are as follows:—

Temperature $(^{\circ}\text{F})$ 5° 10° 15° 20° 25° 30°

Hoar-frost point 7.8° 12.4° 16.9° 21.3° 25.8° 30.2°

Thus at low temperature the hoar-frost point may be substantially higher than either the dry-bulb or ice-covered wet-bulb temperatures.

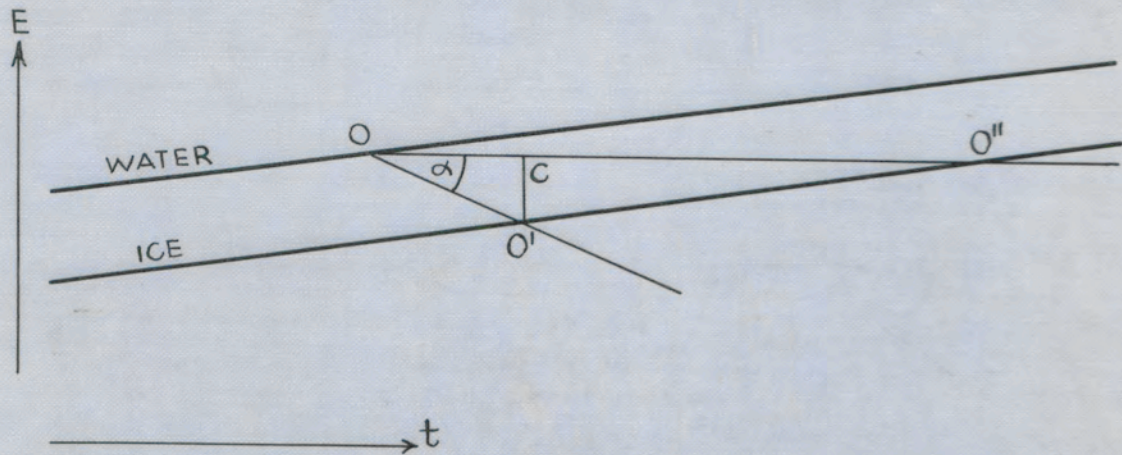


FIG. 1

The rime-point is the temperature of rime deposited from super-saturated air, that is to say, the temperature reached by super-cooled water droplets on solidification. It is clearly equal to the actual temperature of the ice-covered wet-bulb, and it is indeed the absorption of the latent heat set free by the water droplets on solidification which causes the wet-bulb to read higher than the dry-bulb.

Graphical Construction. It is of interest to note that the maximum negative depression of the wet bulb may be derived from vapour pressure-temperature graphs by a simple graphical construction.

The curves marked "water" and "ice" in Fig.1 represent portions of the saturation-pressure-temperature curves, drawn on a scale in which a unit of length represents one millibar in the ordinates and one degree Fahrenheit in the abscissae. Let O be the point corresponding with saturation with respect to water at temperature t . Through O draw a line parallel to the temperature axis, intersecting the "ice" curve in O'' . Also, from O draw OO' , sloping downwards to intersect the "ice" curve at O' , and making with OO'' an angle α , the tangent of which is the constant in equation (1), (2) and (3). From O' draw $O'C$ perpendicular to OO'' . Let t' be the abscissa of O' .

CO' is the difference in the ordinates of the points O and O' and is therefore equal to $E_w - E_i$.

$$OC = CO' \cot \alpha = (E_w - E_i)/A$$

$$\text{Also } OC = t' - t$$

Thus we have $t' - t = (E_w - E_i)/A$ which is identical with equation (1) when e is put equal to E_w .

Thus OC represents the (negative) depression of wet bulb which occurs when the vapour-pressure is equal to the saturation-pressure over water at dry-bulb temperature, and this is the maximum value possible for a given temperature.

Clearly, also, the abscissa of O' represents the hoar-frost point under the conditions postulated.

HALO DISPLAY OF NOVEMBER 14th, 1941.

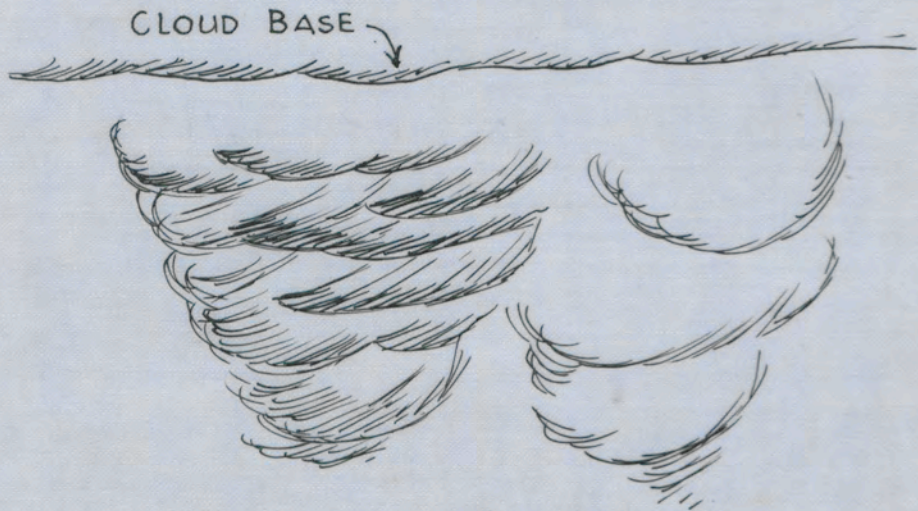
Mr. G. H. J. DAYSH, of King's College, Newcastle-on-Tyne, has sent a number of letters which he has received on the subject of the halo of November 14th. The display was visible at one place or another from about 13h. to 15h. 50m. (G.M.T. but in some of the reports there is uncertainty whether G.M.T. or B.S.T. is intended) but at no one place was it observed for more than an hour, as a patch of cirrus passed over. The 22° halo and mock suns on either side generally appeared first, quickly followed by the 46° halo and the upper arcs of contact to both haloes. Mr. O. Darbyshire reported also bright mock suns on the 46° halo and Mr. O. N. Pumphrey a mock sun at the point of contact of the 22° halo and upper arc of contact.

The most remarkable sketch was sent by Mr. R. P. Atkinson; it shows the 22° halo and mock suns on either side, also the lower arc of contact, lateral arcs of contact and apparently a complete circumzenithal ring tangent to the 22° and arcs tangent to the circumzenithal ring on the opposite side of the sky to the sun. The altitude of the sun at the time was only about 26° so that visibility must have been remarkably clear for the lower arc of contact to be visible. The drawing is too rough for reproduction.

Similar phenomena, including both 22° and 46° haloes, arcs of contact, and mock suns, were seen by Dr. C. Armstrong Gibbs at Windermere shortly after noon on the same day.

CURIOUS CLOUD PHENOMENON.

Mr. J. L. Bennett of Colgate near Horsham sends the accompanying sketch of a cloud formation which he observed on November 2nd. A large rain-squall had passed to the west at 1430, moving NNE. From the end of the cumulo-nimbus cloud an enlarged form of mammatus bulged down, growing with some speed into a form resembling inverted cumulus and finally developed into curtain-like rainfall.



LARGE MAMATUS FORMATION (Descending)



AURORAL NOTES. APRIL-SEPTEMBER, 1941.

Aurora was seen from places in Shetland on 8 nights during April, viz. 1st, 7th, 14th, 15th, 17th, 18th, 25th and 26th. It was also observed from Aberdeen on the 23rd, Skye on the 24th, Kettins on both 24th and 26th, and Craigston (Barra) and Leuchars on the 29th. The phenomenon was not reported again until July 27th and 28th when it was seen from Abbotsinch. St. Abbs Head is the most southerly of several places from which it was observed on August 26th, 27th and 28th. It was seen in Shetland on August 30th and 31st.

There was a marked increase in auroral activity during September, the phenomenon being observed on 12 nights - the highest frequency since March. At Lerwick, on the 4th, diffuse luminous surfaces of moderate intensity were seen after 21h.30m. in the NNW at altitude 30 degrees. On the 14th aurora was reported from two places in Skye and from Buddonness. It was again observed from Skye on the 15th as well as from places in east and northeast Scotland. A single report of its appearance on the 16th came from Nairn.

The auroral display on September 18th, which was of unusual brilliance, was associated with a severe magnetic storm. It was seen in all parts of Scotland, in southwest Ireland, and at places in the south of England. At Lerwick observations were restricted by cloud until 21h.30m. but from then until 03h.30m. continuous records were made. The aurora which was constantly changing in form, was brightest between 22h. and 22h.30m. Bright green and red draperies were active in the northern sky up to 30 degrees altitude at 22h.23m. and these were followed by green and orange draperies low in the WNW and blood red diffuse luminous surfaces in the SW up to 15 degrees with diffuse bundles of rays in the North up to 40 degrees. At Carboist in Skye Mr. Jas. McLean saw luminous green and yellow bands shooting to and fro, also long beams shooting vertically and appearing and disappearing with great speed; at other times the whole sky seemed to be shaking up and down. At Ballingarry in County Limerick, Mr. H. H. Lamb first noticed the aurora about 22h. as waving curtains of white light flashing from West to East across the zenith. In the next half hour flame aurora developed over the entire western half of the sky, with great activity at the zenith, where an irregular auroral crown appeared at times, with pulses of light reaching at times well over into the southern half of the sky. The structure consisted mainly of irregular curtains of light in a roughly

west to east direction across the sky. The display was almost entirely in white light and persisted with undiminished intensity until 22h. It was still visible until fog blotted it out at 24h. At Exeter, Mr. W. N. Lavis observed an auroral bluish glow in the direction N-NNW from 20h. to 22h.30m. This extended up to 75 degrees altitude and exhibited very little change in form over the whole period of observation. The sky was cloudless and the light was enough to pale neighbouring stars. On one occasion between 21h. and 22h. two faint pink vertical streamers intersected by a more diffuse horizontal striation, were observed against the main glow. Reuter reported from New York that a magnificent display of aurora was witnessed there.

Another fine display was seen at Lerwick on the 19th. There was little cloud in the early evening and aurora was observed continuously from 19h.26m. until the sky became overcast at 21h.45m. On this occasion activity was mainly in the east and NE. Bright corona and bands with ray structure of reddish tinge were features of the display which was seen in many parts of Scotland and as far south as East Anglia. On the 20th aurora was reported from West Linton, Skye, Wick and Orkney. In the evening of September 21st. Mr. McLean in Skye observed "one mass of auroral glow in the east and another in the west, with yellow beams shooting from mass to mass at intervals". Stations on the Moray Firth and in Orkney also reported aurora on that night. Wick and Nairn reported its appearance on the 22nd and the latter station on the 24th also. Other auroral observations in September were on the 29th from Wick and Kirkwall and on the 30th from Duntuil (Skye) and Lerwick.

H.E.C.

UNUSUAL CLOUD FORMATION.

The observer at Lord Wandsworth College, Long Sutton, Basingstoke has sent a photograph of unusual cloud formation observed there on the evening of June 17th. The formation was similar to that associated with cell action, connected with heating of the ground by insolation. Captain Douglas writes "the interesting cloud structure was at medium heights, due to upper instability and well above surface convection. On the same number of photographs of somewhat similar (though far from identical) clouds were taken at Tangmere and notes were received from a number of other stations".

A RED RAINBOW.

Mr. J.S. Balk of Oxford reports on September 28th, 1941, "Very red sky at time of sunset with Rainbow, of red colour only, about 18h."

A SUNLIGHT DIAGRAM.

With reference to the diagram in the October Magazine, readers may like to be reminded that there is a similar diagram in Shaw's "Manual of Meteorology", Part I, 2nd edition 1936.

METEOROLOGICAL STATIONS.

A new station at Meltham (Nether End) has been approved. This station is in continuation of the station at Meltham (Harewood Lodge) maintained by the late Mr.C.L. Brook. Mr. S. Morris Bower of Oakes, Huddersfield has been responsible for the setting up of the station and for the organization of the Meteorological work.

CENTRAL METEOROLOGICAL OBSERVATORY, JAPAN.

Professor T. Okada has relinquished his post as Director on account of advancing age. Dr. S. Fujiwhara took his place on July 30th 1941.
