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## THE WET AND DRY BULB HYGROMETER.

BY

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THE wet and dry bulb thermometers form the simplest instrument for ascertaining the humidity of the air, and in some form are in general use. In the autumn of 1917 I began an experimental inquiry into the reduction of their readings. There are two main conditions under which they are used, *i.e.*, in still air or in moving air. Starting with Clerk Maxwell's formula for still air ("Ency. Brit.," 9th Edition, Article Diffusion),

$$p = p_w - \frac{PS_p}{L\sigma} \left( \frac{K}{\gamma D} + \frac{AR}{4\pi CS_p \rho D} \right) (t - t_w) \quad . . . . . (1)$$

where :—

- $p$  is the pressure of aqueous vapour in the air at a temperature  $t$  ;
- $p_w$  the maximum pressure of aqueous vapour at the temperature of the wet bulb  $t_w$  ;
- $P$  the whole pressure of the air ;
- $S_p$  the specific heat of air at constant pressure ;
- $L$  the latent heat of water at  $t_w$  ;
- $\sigma$  the specific gravity of aqueous vapour compared with air ;
- $K$  the thermometric conductivity of air ;
- $\gamma$  the ratio of the specific heats = 1.41 ;
- $D$  the diffusivity of aqueous vapours in air ;
- $A$  the area of the wet bulb ;
- $R$  the radiation constant for the wet bulb ;
- $C$  the electric capacity of the bulb ;
- $\rho$  the density of air.

I tested its validity by replacing the dry air by dry hydrogen ; and by data at reduced pressure in air. The results showed that Maxwell's formula satisfied the data obtained in such a dry still gas as that inside a porous pot soaked in strong sulphuric acid.

The more important condition, *i.e.*, in moving air, was submitted to experiment, and was discussed theoretically. One theoretical method was to take Maxwell's formula for dry air and consider how it should be modified for air in motion. As soon as the velocity is great enough the diffusion effect will be very large compared with the radiation effect ; moreover, the conduction effect would increase *pari passu* with the diffusion effect. Arguing in this way and using the results of experiment, the formula in practice reduces to

$$p = p_w - \frac{PS_p}{L\sigma} (t - t_w) \quad . . . . . (2)$$

This view was put forward at a meeting at the Meteorological Office, and in the discussion Major G. I. Taylor outlined a theory based on the passage of heat and water-vapour through the eddy-free layer next the wet thermometer to the eddy layer beyond. In the eddy-free layer his theory leads to the formula ( $k$  = the calori-

metric conductivity and  $p_e$  the pressure of aqueous vapour at the junction of the two layers and  $t_e$  its temperature)

$$p_e = p_w - \frac{P}{L\sigma} \cdot \frac{k}{D\varphi} (t_e - t_w) \quad \dots \dots \dots (3)$$

Now, since  $\frac{k}{D\varphi}$  for air is nearly numerically equal to  $S_p$  the formula in effect reduces to

$$p_e = p_w - \frac{PS_p}{L\sigma} (t_e - t_w) \quad \dots \dots \dots (4)$$

In the second eddy layer the formula for the exchanges is

$$p = p - \frac{PS_p}{L\sigma} (l - t_e) \quad \dots \dots \dots (5)$$

When the effects of the two layers are combined we have

$$p = p_w - \frac{PS_p}{L\sigma} (l - t_w)$$

a formula the same as (2) above.

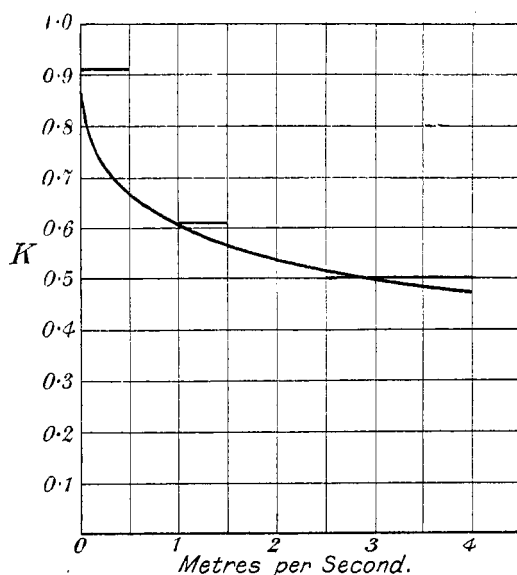
The formula was tested experimentally. A short test tube, 2.3 cm. diameter and 10 cm. long, was closed by a cork with three holes in it, through which passed an entrance glass tube leading to the bottom, an exit tube from near the top, and a thermometer graduated in 1/10ths of a degree. The wet bulb was made by wrapping one or two layers of linen gauze about the bulb of the thermometer and tying this in place with cotton thread. The wet thermometer was moistened by immersing it in a beaker of water before each experiment. To prevent heat from coming from the outside to this apparatus it was enclosed in a larger vacuum-jacketed test tube, and the intervening space was plugged with cotton wool. In some experiments this vacuum-jacket was dispensed with, for the complete experiment only lasts about four or five minutes, and not much heat can get in in that short time. The exit tube was connected to the suction nozzle of a Lennox electrical blower, so that a rapid draught could be maintained through the apparatus. The entrance tube was connected to a tall tower of pumice saturated with strong sulphuric acid in order to give a supply of dry air.

With dry air the following readings were obtained :—

Dry Air °C.	Wet Bulb °C.	Vapour Pressure at the Temp. of Wet Bulb divided by the depression of Wet Bulb.
15.15	3.1	0.477
15.1	2.8	0.472
18.2	4.7	0.460
16.7	4.0	0.474
17.9	4.7	0.483
18.2	4.9	0.476
		0.474 Mean.

The pressure in the apparatus during the passage of the air stream was determined by substituting for the thermometer a pressure gauge containing mercury. This showed that the pressure inside was 25 mm. less than atmospheric when the motor was working at its highest speed. Therefore, the theoretical constant is  $735 \times 0.2375 / 603 \times 0.622$ , or 0.473, which is in good agreement with the experimental result.

The velocity of the stream of air was ascertained by means of an air meter (Negretti & Zambra), fitted to the side of a box from which the air was drawn. The velocity of the air was found to be 86 feet per minute, and this multiplied by the ratio of the square of the diameter of the aperture of the air meter to the square of the diameter of the tube gave 3.92 metres per second for the velocity of the



Variation with air-speed of the coefficient  $K$  in the convection formula.

air passing over the wet bulb. Further experiments were made with hydrogen and with carbon dioxide, to which we have not space to refer, but the results were in agreement with the theory.

Some experiments were made with the same apparatus to measure the amount of aqueous vapour present in air. For this purpose the apparatus for delivering dry air was removed and the air from the room drawn in with the same velocity. At the same time observations were made with Regnault's dew-point apparatus to determine the dew-point and thus obtain the true aqueous pressure in the air.

Arising from these experiments and other data it was possible to draw a curve representing the value of the constant by which the depression of the wet thermo-

meter must be multiplied in terms of the velocity of the air up to 4 metres per second. The diagram is shown on previous page.

This refers to air pressure of 760 mm. in the formula  $p = p_w - K(t - t_w)$ .

The formula may be called the convection formula.

The three horizontal lines in the diagram represent Pernter's three values of the constant, *i.e.*,

0.91 for calm air velocity 0 to 0.5 m. per second.

0.61 for light winds „ 1 to 1.5 „ „

0.50 for strong winds velocity above 2.5 m. per second.

A fuller description of this method is given in the new “ Dictionary of Applied Physics.”

The convection formula may be applied to explain the “spheroidal” state. A drop of water in a platinum basket in the centre of a flame evaporates rapidly and its temperature will be  $t_w$  in our expression. Again, the formula illustrates the extinction of flames by a shower of falling drops. Reference was made to these applications at my lecture before the Royal Institution, April, 1921.