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THE PHOTO-ELECTRIC NUCLEUS COUNTER AS HYGROMETER

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Summary — Hygrometric measurements on room air were made with a NOLAN-POLLAK nucleus counter from which the lining of blotting paper had been removed. The dew point can be determined from the critical overpressure for condensation on nuclei. Satisfactory agreement with the values given by a ventilated wet and dry bulb hygrometer was obtained. The correction required is small since condensation occurs on ordinary atmospheric nuclei when the temperature is brought to about 0.3°C below the dew point.

Zusammenfassung — Es wurden Feuchtigkeitsmessungen der Zimmerluft mit einem NOLAN-POLLAK Kernzähler gemacht, in welchem das Futter aus Fliesspapier entfernt worden war. Der Taupunkt kann aus dem kritischen Überdruck, der für die Kondensation an den Kernen notwendig ist, bestimmt werden. Es wurde zufriedenstellende Übereinstimmung mit den Angaben eines ventilierten ASSMANN-Psyehrometers gefunden. Die erforderliche Korrektur ist klein, da die Kondensation an gewöhnlichen Kernen der Luft stattfindet, wenn die Temperatur auf einen um 0,3°C verminderten Taupunkt gebracht wurde.

We describe in this paper a method of determining the hygrometric state of air by photo-electric measurements on the cloud formed by an adiabatic expansion. A NOLAN-POLLAK photo-electric nucleus counter (1) with some minor alterations was used. The experimental procedure was to determine the critical overpressure corresponding to the onset of condensation. For comparison a simultaneous determination of the dew point was made by means of a ventilated wet and dry bulb hygrometer.

The equations for an adiabatic expansion are

\[ \frac{T_1}{T_2} = \left( \frac{v_2}{v_1} \right)^{\gamma - 1}; \quad \left( \frac{v_2}{v_1} \right)^\gamma = \frac{P_1}{P_2}. \]

In the normal use of the photo-electric counter the final pressure \( P_2 \) is equal to the atmospheric pressure \( B \), and the initial pressure \( P_1 = B + O \), where \( O \) is the overpressure. In the present work we determined the critical overpressure

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required to reduce the temperature from room temperature \( T_1 \) to the dew point \( T_2 \).

From equation (1) we obtain

\[
\frac{T_1}{T_2} = \left( \frac{P_1}{P_2} \right)^{\frac{1}{\gamma}} = \left( 1 + \frac{O}{B} \right)^{\frac{1}{\gamma}}.
\]

This gives approximately

\[
1 + \frac{T_1 - T_2}{T_2} = 1 + \frac{\gamma - 1}{\gamma} \cdot \frac{O}{B}
\]
or putting

\[
T_1 - T_2 = e
\]
\[
e = \frac{\gamma - 1}{\gamma} \cdot \frac{T_2}{B}.
\]

Since the percentage variations in \( B \) and in \( T_2 \) are not large we thus find that the critical overpressure is approximately proportional to the difference between the actual temperature and the dew point. If we take \( \gamma = 1.37 \), \( T_2 = 280^\circ \) and \( B = 76 \text{ cm Hg} \) we find that \( e \) in degrees Celsius is equal to \( O \) in cm Hg.

An estimate of the error resulting from the approximation may be got by retaining another term in the expansion. We find that the right hand side of equation (2) is then multiplied by \( 1 - 1/2\gamma \cdot O/B \). When the dew point is low the critical overpressure is large so that the ratio \( e/O \) will tend to decrease as the overpressure increases. If the values of \( e \) are plotted against \( O \) we will obtain, instead of the straight line indicated by the approximate treatment, a curve concave to the overpressure axis.

\textbf{Condensation of nuclei} — In the discussion so far we have assumed that condensation occurs on a plane water surface. In examining condensation on a nucleus three factors must be considered: (i) the presence of an electric charge, (ii) the curvature of the surface and (iii) the hygroscopic nature of the nucleus.

The effect of an electric charge in promoting condensation on atmospheric nuclei is negligible since the radius is about \( 3 \times 10^{-6} \) cm and a single electronic charge just begins to have appreciable effect at a radius of about \( 2 \times 10^{-7} \) cm. The vapour pressure \( p' \) in equilibrium with a spherical droplet is greater than the vapour pressure \( p \) in equilibrium with a plane surface. The ratio is given by the formula

\[
\frac{p'}{p} = \exp \left( \frac{2S}{r} \cdot \frac{M}{RT} \right)
\]

where \( S \) is the surface tension, \( M \) the molecular weight of water, \( R \) the gas constant, \( T \) the absolute temperature and \( r \) the radius. The vapour pressure at the surface of a solution is less than over pure water and the percentage decrease is roughly proportional to the concentration of the solute.

With condensation nuclei in general the increase in vapour pressure due to curvature is offset to a large extent by the diminution produced by the presence of dissolved material. NOLAN & MacGORMAN[2] found that for condensation
on atmospheric nuclei of radii between $1 \times 10^{-6}$ and $3 \times 10^{-6}$ cm, the volume expansion percentage required in saturated air was between 0.5 and 0.1. The volume expansion percentages required for condensation on nuclei composed of pure water may be evaluated as 1.8 and 0.62 at 16°C for radii $1 \times 10^{-6}$ and $3 \times 10^{-6}$ respectively. Since the hygroscopic effect balances so large a portion of the curvature effect the correction to be applied to our observations is quite small. We will base our correction on the figures of Nolan & MacCormac and take a volume expansion percentage 0.3. The correction can be applied either to the temperature fall or to the overpressure.

Equations (1) give

$$\frac{T_1}{T_2} = (1.003)^{1/4} = 1.0012$$

$$T_1 - T_2 = 0.0012 \ T_b = 0.3^\circ C$$

$$1 + \frac{O}{T_b} = (1.003)^{1/4} \text{ so that } O = 0.3 \text{ cm Hg}.$$ 

This means that with saturated air in the counter an overpressure of 0.3 cm Hg which gives a volume expansion of 0.3 per cent and a temperature fall of 0.3°C is necessary on the average for condensation on ordinary atmospheric nuclei. Owing to variation in the size and nature of the nuclei this figure 0.3 can vary between 0.5 and 0.1 so that for example our temperature correction which we will take as $-0.3^\circ C$ may be $0.2^\circ C$ in error.

Experimental Procedure — The apparatus was a modified Nolan-Pollak photo-electric nucleus counter. The blotting paper lining was removed and the filter normally used to purify the overpressure air was replaced by a large glass bottle. Room air was drawn through the counter and the bottle by means of an electric pump. During the filling readings of a ventilated wet and dry bulb hygrometer were made. The counter was closed and pumped up to a certain overpressure. An expansion was made and the galvanometer reading noted. The counter was then pumped up to a new overpressure and the experiment repeated. In this way a series of readings of overpressures and extinctions was made and the results were plotted as a graph. A sample is shown in Fig. 1. For extinctions up to about 12% the graph is approximately a straight line. The point of intersection with the pressure axis is taken as the critical overpressure.

In the method just described the same sample is retained in the counter during a series of readings. A second method is to refill with room air for each reading. Comparison showed that the two methods gave the same value for the critical overpressure. The slope of the line was however somewhat larger with the refilling method. This result is only to be expected as in the first method loss by diffusion and by coagulation occurs during the course of an experiment. Since we wished to determine the intercept and not the slope we adopted the first method which was quicker and more convenient.

The minimum reading of the galvanometer is taken after the formation of the fog. The galvanometer deflection then increases rapidly to the original value, which is usually adjusted to 100 divisions. The rapid decrease of the extinction is due to evaporation of the droplets. The cloud formation entails no loss of nuclei except a loss by fall under gravity of the droplets. This loss is very small since
the lifetime of the droplets is short. The period of the galvanometer was about two seconds so that large extinction readings may, owing to evaporation, be less than the true value. The value determined for the critical overpressure is not, however, affected by the rapid disappearance of the fog.

Fig. 1 - Variation of extinction with overpressure.

Fig. 2 - Relation between critical overpressure and the difference between room temperature and the dew point.
The results of a typical experiment are as follows:

Room Temperature = 16.1°C, Dew Point = 7.5°C; e = 8.6°C, O = Critical Overpressure = 9.05 cm Hg.

We determined the critical overpressure graphically as indicated in Fig. 1, usually with fewer readings. Four or five points with extinctions between 1 and 10% were normally sufficient to fix the critical overpressure.

The results of the simultaneous measurements of e and O are shown in Fig. 2. The points lie approximately on a straight line. We have drawn this line, as previously explained, to cut the overpressure axis at 0.3 cm and the temperature axis at — 0.3°C. This correction is so small that its magnitude cannot be deduced from our experiments. The slope of the straight line drawn is 1°C/cm Hg giving from equation (2) a value of γ = 1.37. During the course of the experiments the maximum and minimum values of the atmospheric pressure were 77.3 cm and 74.2 cm and of the room temperature 20.6°C and 16.1°C. We have thus confirmed the approximate equation (2) under the conditions of small variations in pressure and temperature for which it applies. Our results are not of a sufficiently high degree of accuracy to show the curvature indicated by the closer approximation.

Some experiments, not shown in Fig. 2, were performed with the counter lagged on the outside with cotton wool. These experiments indicated that γ for the lagged counter was slightly less than for the unlagged counter. The difference was so small that we cannot in view of the scatter shown in Fig. 2 regard it as an established result.

Since the completion of these experiments two previous applications (3, 4) of the fog chamber to hygrometric determinations have come to our notice. In both cases the onset of the fog is detected visually.

REFERENCES