The deviation of this quotient from the normal value gives the factor used in the equation. The constant k is seemingly based on the 6.8-year rainfall cycle of northern Peru and is to be applied only in those years when rains are due according to the cycle. It is applied in the sense that there will be an intensification of the drought in the east monsoon every 6.8 years.

SUMMARY OF RESULTS

1. It seems possible to calculate approximately in the first days of May the rainfall in Java in the second half of the east monsoon, that is in most cases July, August, September, October, by a formula in which the independent variables are only three meteorological elements drawn from stations in the neighborhood.
2. The confidence which that formula inspires is based on the fact that it yields satisfactory results in almost every case of a sequence of 47 years in which control is possible and has yielded the right result the first time it was applied, viz, in 1926.
3. Dry and wet east monsoons are so systematically distributed in a seven-year and a three-year cycle, that even without applying our rainfall formula we are able to indicate correctly at least most of the very dry and very wet ones.

Correction is required in the first place because many sun spots keep pressure lower and east monsoons wetter than normal and few sun spots keep pressure higher and east monsoons drier than normal (regular cases).
4. Some unknown influences may for some time disturb the regular scheme (pathological cases).[1]
5. Sudden rises of pressure and corresponding droughts occur at sun-spot minima (singular cases).
6. Our rainfall formula masters the regular and pathological cases; it is, however, powerless with respect to singular cases, such as the east monsoons of 1913 and 1923.

LITERATURE CITED

(1) BRAAK, DR. C.
1919. ATMOSPHERIC VARIATIONS OF SHORT AND LONG DURATION IN THE MALAY ARCHIPELAGO AND THE POSSIBILITY TO FORECAST THEM. Verhandelingen No. 5 Koninklijk Magnetisch en Meteorologisch Observatorium te Batavia, Java.

[1] The author uses the word "pathological" merely for identification purposes. A used it means years in which some outstanding difference from the results found in normal years appear.

RECENT CONTRIBUTIONS TO HYGROMETRY

By S. P. FERGUSSON

During the past 10 years there has occurred an encouraging increase in the number of investigations and publications relating to hygrometry, a large part of which is due to the growing use of "air-conditioning" processes where the quality of a manufactured product depends upon the control of atmospheric humidity. Of the works reviewed briefly in this note, the papers by Dr. A. Norman Shaw, the "Discussion on Hygrometry" and papers in the "Dictionary of Applied Physics" already are well known to physicists, but are included in order to bring them before the staff of the Weather Bureau.

(1) A. NORMAN SHAW.
IMPROVED METHODS IN HYGROMETRY. (Trans. Roy. Soc. of Canada, Series III, Vol. X, 1916).
RELATIVE HUMIDITY. (In same Transactions, Vol. XI, 1917.)
(2) SIR NAPIER SHAW, EZER GRIFFITHS, F. J. W. WHIPPLE AND OTHERS.
A DISCUSSION ON HYGROMETRY. (Proc. Phys. Soc. London, Vol. XXXIV, 1922.)
(3) S. SKINNER.
HUMIDITY. (Article in "A Dictionary of Applied Physics" by Richard Glazebrook and others, Vol. 3, 1924, published by Macmillan, London.)
(4) GEORGE PORTER PAINE.
THE AERODYNAMICS OF THE PSYCHROMETER. (Annals, Astron. Obs. of Harvard College, Vol. 87, Part 1, 1925.)
(5) ARNOLD ROMBERG and L. W. BLAU.
A NEW HYGROMETER. (Jour. Opt. Soc. of America, Vol. 13, No. 6, December, 1926.)
(6) HERMANN BONGARDS.
FEUCHTIGKEITSMESSUNG. (Published by R. Oldenbourg, München and Berlin, 1926.)
(7) AMAD NATH PURI.
INVESTIGATIONS ON THE BEHAVIOR OF HYGROMETRIC HAIRS. (Quar. Jour. Roy, Met. Soc. Vol. 53, April, 1927.)

(1) The first paper describes experiments with several hygrometers of simple construction which apparently have an accuracy greater than that of instruments in common use. Data are given from two instruments, both of the modified chemical type, one measuring the vapor-pressure and the other the varying weight of a quantity of phosphorus pentoxide; these instruments probably are very satisfactory in the laboratory but are not suitable for continuous use by meteorological observers. Of greater interest and importance to meteorologists is the "Summary of the Limitations of Hygrometric Methods in General Use," based on the author's studies, abstracted as follows:

The chemical and vapor-pressure methods usually are elaborate and require expert attention and "research" conditions, which, if available and the conditions are constant, admit of determinations of humidity within 0.1 per cent of its true value; but, under ordinary conditions errors of less than 2 or 3 per cent are difficult to eliminate. These methods are almost useless for the examination of a rapidly varying humidity, giving merely the average value during the time of observation.

With dew-point methods, under the most favorable circumstances, an accuracy of greater than 1 per cent can not be assured. If the relative humidity is less than 20 per cent or if the temperature is below 5° C., errors as large as 10 per cent may easily occur.

With the psychrometer, under the best conditions, a good constancy of repetition may be obtained but an absolute accuracy of within 2 per cent can not be assured. If the wet covering and attention to its ventilation are neglected, errors of greater than 5 per cent may develop under apparently normal conditions. If either the relative humidity or the temperature is low, or if the relative humidity is approaching 100 per cent the errors may be larger than 10 per cent. The former conditions for such errors are very common during the winter in cold climates. Inside steam-heated buildings, for example, the relative humidity will, when the temperature is below −30° C. outside, be sometimes as low as 5 per cent and yet be indicated as high as 20 per cent on an instrument which, without alteration, will record satisfactorily under average summer conditions.

Hygrometers of expansion, especially those employing hair, gut, or horn need very frequent recalibrations and in a few months may become almost useless. After subjection to extreme conditions there are often large "after effects" which vary in a complicated manner. If however these instruments are compared frequently with others over a large range of humidities they are the most convenient, because their sensitiveness is great, the time needed for a determination of humidity is short and the procedure merely that of reading a scale or chart. They have, perhaps, been over-maligned by many observers, but it must be admitted that the necessity for frequent recalibration renders them unsuitable for accurate work outside the laboratory.

The second paper discusses from the viewpoint of physics and physiology the confusion due to giving relative humidity and absolute humidity equal prominence and suggests that "treatment of the subject can be kept quite clear if the term 'relative humidity' is kept in its proper place as a derived quantity of secondary importance."

(2) This excellent work, probably the most thorough presentation of modern technique by English authorities, comprises 8 memoirs and 18 short notes in the form of a discussion. An introductory chapter, "The Measurement of Atmospheric Humidity," by Sir Napier Shaw,

discusses the subject from the viewpoint of the daily meteorological observer who must be regarded "as a tool user, not as a tool minder, still less as a toolmaker. For that reason, meteorological practice in the measurement of humidity is limited to the wet and dry bulb thermometers, which are used almost everywhere, and the hair hygrometer, which is used for the term hour observations in Norway and for self-recording hygrometers everywhere." The author's remarks on the two methods are condensed as follows:

There is little difficulty about the use of the wet and dry bulb so long as the temperature of both remains above the freezing point. The formula for reduction depends to some extent upon wind velocity, and in dry climates, like that of Egypt, a small error in formula may lead to ridiculous results in practice; if anything vital turned on the results, there is little doubt that a system would be evolved without difficulty. But as soon as the freezing point is passed the wet bulb ceases to be an effective instrument. The water has no definite freezing point, but freezes at all sorts of temperatures, and when the water is frozen the capillary action, upon which the moistening depends, ceases altogether. The directions for the treatment of the wet bulb during frost are palliatives designed to carry on in an occasional emergency. Nobody in London could possibly satisfy himself from the evidence at his disposal whether a reading of humidity during frost entered in a schedule from, say, Yarmouth, or on board a ship, represented frozen bulb, supercooled wet bulb, semidry bulb or dry bulb. In these circumstances, equality of reading of wet bulb and dry bulb, the most probable occurrences in the circumstances, has no effective meaning. * * * Moreover, below the freezing point the amount of water vapor in the atmosphere and its variations becomes very small. There is very little to go upon when dealing with absolute measures. It is, however, remarkable that the shrinkage and slacking of cordage and other results upon animal and vegetable fibres are apparently as effective as at any other temperature.

The conclusion at which I have arrived is that the wet bulb is useless for temperatures just below freezing and should be discarded. Descriptions of the endeavor to find a suitable formula abound in meteorological literature; but practically, the subject has not advanced at all in my time.

So far as I know, the hair hygrometer is the only instrument which is available in those circumstances to give a reading which can be interpreted. Since the publication of Regnault's classical memoir, physicists have been very shy of it, because it offends the first principles of a physical laboratory; it does not always repeat the same reading in the same physical conditions. It suffers from age and misuse and other infirmities. But in view of the general failure of more orthodox methods, the prejudice of the physical laboratory against the instrument is a little overdone and unreasonable. I suppose that there is a limit beyond which even the most accurate physical experiment does not repeat itself. * * * And in an atmosphere where rejoicing in the triumphant accuracy of one part in hundred thousand is a common experience, it is annoying to be brought up by a matter that can not keep steady within 5 per cent. Yet hair is apparently a more definite physical quantity than wet muslin.

Certain it is that the story which the recording hair hygrometer tells of the variation of the humidity of the atmosphere at any temperature is an extremely romantic and interesting one; and even when its tabulated figures are erroneous, its sequences are valuable evidence of the course of events.

I have little experience of its working. I do not much like covering it with a damp cloth or wetting the hairs and calling the reading 95 per cent; and yet, considering that the atmosphere is always in turbulent motion, and a process of mixing is always going on, it is really doubtful whether the actual humidity of a small portion of the atmosphere is a physical quantity to be measured by any instrument freely exposed to the passing air.

In the longest paper of this series Dr. Ezer Griffiths, of the National Physical Laboratory, describes original experiments made with the object of developing suitable apparatus for the measurement of humidity at low temperatures. "The three classical methods—the wet and dry bulb hygrometer, the dew-point apparatus, and the hair hygrometer—were studied and so modified that they could be used in a low temperature room inaccessible to the observer. An important feature of the work was the elimination of artificial disturbance of conditions in and near the measuring instruments caused by the presence of the observer, etc. New instruments described (of special interest to meteorologists) are a continuously recording resistance-thermometer type of psychrometer having an automatic cam device for rapidly dipping and withdrawing the bulb at periodic intervals from a reservoir of water, a distant reading type of dew-point apparatus in which the change of reflecting power of a cooled surface (due to condensation) was measured by a minute thermopile, and a distant reading hair hygrometer in which the clock drum of the ordinary recorder was replaced by a tubular rheostat. The pointer (of the recorder) was pressed into contact with the rheostat when a reading was desired; the two portions of the resistance winding then constituted the two arms of a Wheatstone's bridge. A number of other forms of hygrometers were also studied and a convenient form of apparatus for the calibration of hygrometers over a wide range of humidities is described." From lengthy experience with various methods the author concludes that the dew point is the most convenient of all methods for low-temperature work; consequently, it was employed as a standard of reference for most of the work recorded in his memoir.

In "The Theory of the Hair Hygrometer," Dr. F. J. W. Whipple, now superintendent of Kew Observatory, discusses papers by de Saussure, Regnault, Srenevsky, and others; a summary of this memoir follows:

Microscopic examination of a hair shows that it contains numerous cells; some are filled with coloring matter whilst others contain more or less water. According to Srenevsky, when the hair is in a saturated atmosphere these pores are filled to overflowing. On the other hand, in a comparatively dry atmosphere the water in each cell will be bounded by a curved meniscus. The tendency to reduce the radius of curvature of the meniscus strains the cell walls. (When the hair is saturated there is no such strain.) It may be expected that, if the cells are elastic and are deformed in accordance with Hooke's law, the contraction of the hair as it dries will be a simple function of the relative humidity.

After discussing mathematically the effects of varying vapor pressures upon the cells of a hair the author concludes that

* * * the theory leads to the simple result that the contraction of the hair from its length when saturated is proportional to the logarithm of the relative humidity of the atmosphere. The theory should only hold good provided that the drying is not carried so far that many of the cells lose all their water. It is also certain that Hooke's law will not hold in extreme cases.

An important application of the theory is that hair hygrometers should not be used in dry atmospheres, where the contents of the hair cells may completely evaporate. It is well known that in such circumstances the readings are apt to be unreliable. No attempt should be made to carry the calibration of a hygrometer down to very low humidities; the range from 100 per cent to 20 per cent should suffice for almost all purposes.

"The Wet and Dry Bulb Hygrometer," by Principal S. Skinner, is an experimental inquiry based on Clerk Maxwell's formula for still air modified for air in motion.

The "Note on Psychrometry in a Wind Channel," by R. A. Watson Watt, describes experiments showing that the formula used in reduction of data from the ventilated psychrometer applies at air speeds of 25 to 40 meters a second without appreciable change of constants from those appropriate to a speed of 4.5 meters a second.

The other memoirs and the discussion contain much that is of interest to meteorologists, but are largely devoted to industrial uses of hygrometers.

(3) This is a brief summary of present-day technique including descriptions of standard measuring instruments and humidifying systems. (It may be added that the same volume contains authoritative chapters on meteorology and allied subjects extremely useful to the student and investigator.)

(4) This work, conducted under the auspices of the National Research Council, describes "an investigation

of the magnitude of the combined effects of external work, viscosity, heat conduction, and turbulence on the state of moist air flowing past an obstacle with a view to an experimental determination of an accurate psychrometric formula"; this investigation, taking its departure from the hydrodynamic equations and the Maxwell diffusion equations, has fallen into five parts, the main results of which are outlined in five papers:

I. Theory and Experiments Relating to Energy Transformations in a Jet of Air.

II. Experiments Relating to Energy Transformations in the Region of Eddies Set up by an Obstacle in a Jet of Air.

III. Theory and Experiments Relating to Energy Transformations in the Region of Eddies set up by a Wet Obstacle in a Jet of Moist Air.

IV. An Aerodynamic Formula for the Psychrometer and its Experimental Verification.

V. Verification of the Aerodynamic Theory of the Psychrometer in the Case of a Small-Scale Apparatus.

The methods and apparatus were carefully planned and elaborate, the essentials being a small wind tunnel and accessories in which the thermometer bulbs were exposed. A special chemical hygrometer and a modified Assmann psychrometer were used as reference standards and the experimental data used in developing the new psychrometric formula were obtained chiefly from wet and dry bulb thermocouples, which were accurate within about 0.006° C. The practical validity of the formula was tested by means of the modified Assmann instrument, an important improvement in which consisted of a partition placed in the central tube to prevent turbulent mixture of air currents from the separate thermometers. The tests indicate that, at ordinary room temperatures and through a range of relative humidity from 12 to 76 per cent, the computed and observed values of humidity agreed within about 1 per cent. One result of interest is that, increasing the velocity of ventilating current to 15 meters a second causes spraying of water from the wet bulb.

(5) The hygrometer described is simple and continuous indicating; a value of the humidity is obtained by balancing a column of atmospheric air against one of air saturated with water vapor and observing the effect, on a suspended vane, of the difference of pressure due to different densities. It is more sensitive than the Regnault-Alluard type of dew-point instrument and can be made a hundred times as sensitive if required. The feature perhaps most important to meteorologists is that the instrument may be used as a standard of reference at temperatures below 0° C.; the table of data indicates satisfactory determinations at −15°, hence, that we now have a means of standardizing hair hygrometers at temperatures where the psychrometer is useless.

(6) This is probably the most complete and thorough of recent textbooks on hygrometry. Its 322 pages contain just the information most useful to all who are interested in the many applications of hygrometry in science and industry. The first 40 pages contain a discussion of the physics of gases and water vapor, including the kinetic theory of gases, the laws of Boyle, Mariotte, Dalton, and Gay-Lussac, the phases (forms) of water, weight and density, heat capacity, and the basic methods of measuring pressures and temperatures, with appropriate mathematical formulæ and illustrations of simple measuring instruments.

The remainder of the volume is a description of methods of measurement, with many illustrations of apparatus suitable for different purposes or needs, hygrometrical tables, and a bibliography.

The chemical or "absolute" method is well illustrated by gravimetric and volumetric instruments of Brunner, Baumhoser, Schwackhofer, Petterson, Rudorff, and Edelmann, the saturation process by instruments of Rudorff and Wolfert, and the low-temperature apparatus of Sonder. The condensation method (dew-point) is represented by 13 instruments, beginning with Daniell and ending with Bongards, of which perhaps the best known are those of Regnault, Alluard, and Crova.

The evaporation method (psychrometric) is introduced by descriptions of atmometers of Wild and Piche, followed by a discussion of the theory of the psychrometer, including the behavior of the instrument in moving and still air, with various coverings and with frozen covering. Typical instruments are described, of which the more important are the well-known Assmann psychrometer, meteorological psychrographs by Pastorelli & Rapkin, industrial instruments by Parks-Cramer, and electrical and distance-recording instruments by Hartmann and Braun, Brown, and Siemens and Halske.

Following the section on the psychrometer, nearly all of the last third of the volume is devoted to methods of measurement by means of hygrometric substances, of which 71 pages are assigned to the hair hygrometer. Methods of preparation of materials, the evaluation of scales, the behavior and durability of hair, and apparatus for testing instruments are described in considerable detail and well illustrated. Eight direct-reading instruments by de Saussure, Koppe, Lambrecht, and others; four hygrographs by Richard, Fuess, Lambrecht, and Edney; and a distance-recording instrument by Lambrecht are well described and illustrated. The use and possibilities of optical and electrical devices are discussed briefly.

A translation of this excellent work and a new text of the kind in English are greatly to be desired.

(7) Quoting the author's summary, this paper describes a study of four types of hair hygrometers in which the total load on the hairs consists of a weight. These were taken through a series of humidity changes controlled by sulphuric acid-water mixtures. It is shown that, when the hair is loaded with a weight of two grams, or more, it undergoes a slow extension which extends over a period of several weeks. Hair under a smaller load shows no such effect and the readings at various humidities can be reproduced with sufficient accuracy to measure humidity within 2 per cent.

Alterations in length of hair due to changes in humidity show a hysteresis effect which is apparently in the reverse direction to that when measurements are taken in terms of change of weight.

A simple form of weight hair hygrometer has been described which can be used for measuring the vapor pressure of moist substances. (This consists of a small quantity of hair, cut into small pieces and cleaned by washing with benzine, placed in a weighing bottle.)

Two facts of interest are indicated by this review: (1) Although through improvement of methods it is now possible to determine the humidity of a measured quantity of air with fair precision, there is no process capable of indicating the humidity of the free air with an accuracy of within ±2 per cent, even under favorable conditions. (It may be that, as in the case of anemometers, free-air conditions will not permit greater accuracy.) (2) An increasing tolerance for the hair hygrometer on the part of physicists. It is being realized that unsuspected errors of the psychrometer and other forms of hygrometers, due to conditions of observation, etc., may be larger than those hitherto attributed to the hair hygrometer.