Hygrometry

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HYGROMETRY.

PAPER BY MR. W. A. DIXEY, *Vice-President.**Read before the Optical Society on February 19th, 1903.*

THERE are three qualities of the air, its temperature, its pressure and its humidity, which are of interest to everyone, and which form a frequent subject of comment in our daily life and conversation; and to measure the temperature of the air we have the thermometer, and to measure its pressure we have the barometer, and to measure the humidity of the air we have the hygrometer. And while everybody has a thermometer and knows how to read it, and most people have a barometer and think they know how to use it, how few people outside a laboratory or a meteorological station own a hygrometer, or, if they had one, would know how to get any information from it; and this although in some respects the measurement of the humidity of the air is of more value and of more interest than the estimation of its temperature or pressure.

And I think there are two main reasons for the general neglect of the science of hygrometry; and the first is a want of knowledge of its principles, and the second is a lack of a simple, easily read instrument for measuring the degree of humidity. And as I suppose Opticians are chiefly to be blamed on both counts, I thought that would serve as an excuse for introducing to you to-night a subject which is not perhaps strictly optical.

So that the object I have in view in reading this paper is to try to raise your interest in the subject of hygrometry, and perhaps to indicate some simpler, and more generally acceptable, form of hygrometer than the instrument which we now usually associate with the name.

And now let us start at the beginning, and ask ourselves what hygrometry is.

Hygrometry may be defined as the measurement of the amount of water present in the air in the form of aqueous vapour.

We know that the air consists of a mixture of gases, chiefly

nitrogen and oxygen, in more or less constant relative quantities. And permeating this mixture of gases, to be regarded as in it but not of it, there is always a quantity of aqueous vapour, or water in its gaseous form.

It is one of the most familiar properties of air that it has the power of sucking up water, and absorbing it in the form of vapour. From the point of view of the water we call this *evaporation*.

The amount of vapour present in the air at any given time is very variable, and depends upon a variety of conditions. One of the tasks of hygrometry is to determine the exact amount. If we have an instrument which will show us the number of grammes of water in a cubic meter of air we arrive at what we may call the *absolute humidity* of the air.

But this is not the only task of hygrometry, nor indeed the most practical and most interesting. We have to realise what is meant by *relative humidity*. The air can only absorb a certain quantity of water; when it has reached this limit it is saturated, and can contain no more. If more vapour is projected into it when in this saturated condition, the extra vapour is at once deposited in the form of rain, or dew, or a film of water upon any convenient surface.

This limit at which air becomes saturated is called the *dew point*. Now it is important to notice that the position of the dew point, or the point of saturation, is dependent upon the temperature of the air. Hot air will contain a much larger quantity of vapour without becoming saturated, than will cold air. You may make a scale to compare with the scale of the thermometer of the maximum amount of water that the air will contain at each degree of temperature. Thus at

30 ° F	the air is saturated when 1 cubic meter contains 4.5 grms.
40°	" " " " " 6.5 "
50°	" " " " " 9 "
60°	" " " " " 12 "

and so on.

So that supposing we have a cubic meter of air, and in that cubic meter of air 8 grms. of water in the form of vapour, at a temperature of 60° the air will be fairly dry, as it contains only 8/12 or 2/3 of the moisture which it can hold. But if the same air with the same amount of vapour is cooled down to 50°, it

will be very damp air, as at that temperature it contains $\frac{8}{9}$ of its possible maximum. And if it is further cooled down to 40° it passes the dew point, and while 1.5 grms. (*i.e.*, 8-6.5) is deposited in the form of water, the air remains fully saturated.

So that here you see we have something different from absolute humidity. It is a relative humidity, and what we want in the instrument which is to measure for us the relative humidity of the air is a scale divided to 100 parts, of which the zero represents absolutely dry air, and the 100 completely saturated air. Such an instrument will tell us the percentage of saturation, or the relative humidity of the air.

Let us now consider what means we have for measuring the amount of water vapour in the air.

Perhaps the most obvious is the method of absorption. A given volume of air is made to pass over some substance which will entirely absorb the moisture in it. The difference in weight of the absorbent material before and after the experiment will tell us the weight of moisture that was in the given volume of air. In this way we get the absolute humidity.

If we reduce this to the number of grms. per cubic meter, and compare the result with the table of temperatures and maximum weights, we can read off at once the dew point; and the relative

humidity is calculated from the formula $\frac{t \times 100}{t'}$ where $t =$ the

elastic force of vapour (which is the same as the weight of water in grms.) at the dew point, and $t' =$ the *e.f.v.* at the temperature of the air when the experiment was made.

The best absorbent to use in the experiment is strong sulphuric acid. A U tube may be filled with small pieces of pumice saturated with the acid. One arm should be connected, by means of an airtight fitted tube, with a large bottle filled with water. The tube passes airtight through the cork to the bottom of the bottle. Another tube bent as a syphon passes through the cork to the bottom of the bottle, and serves to draw out the water, and so maintain a constant flow of air through the U tube.

The experiment is one that is easily carried out in a physical or chemical laboratory, and affords, as I say, perhaps the simplest and most obvious means of measuring the amount of moisture in the air.

But it remains a laboratory experiment, and the principles upon which it is based do not lend themselves to the construction of an instrument which could be easily read or interpreted; and that is the chief requirement in an instrument which is to be used by the general public.

Another way of measuring the hygrometric state of the air is to find directly the position of the dew point. Daniell's, Dines's and Regnault's hygrometers have all this object, and I have here a modern form of Regnault's hygrometer which is the simplest and most practical instrument of this class that I have seen.

The physical law on which the instrument is based I have already alluded to, and common illustrations of the law fall within the observation of everybody. If you pour ice-cold water into a glass in a hot room, the surface of the glass quickly becomes covered with small beads of water. The reason of this is that the mass of cold water rapidly reduces the temperature of the layer of air surrounding the glass. This layer of air, which at its former temperature was capable of containing all the vapour with which it was charged, as it is cooled, reaches and passes the point of saturation; it can no longer contain the same amount of vapour, and the excess is deposited in the form of water on the surface of the glass. You will see that if this cooling process were conducted gradually, and if we had a thermometer in the glass of water, we could observe the exact temperature at which water began to be deposited, and this would give us the dew point.

That is exactly the principle of this instrument. Here is a metal cup with a polished surface on which we can easily observe the first appearance of the dew; into the cup is inserted a thermometer to mark the temperature; the glass screen is to guard the instrument from the breath of the observer; into the metal cup I pour a small quantity of ether, and by forcing air bubbles through the ether by means of the rubber bellows I cause the ether to evaporate, and so reduce its temperature. The thermometer marks my progress. I carefully watch the polished surface of the cup, and at the first appearance of the dew I note the temperature. This gives me the dew point; and from this I can, as before, calculate if I wish the relative and the absolute humidity of the air.

Here we have an instrument practical and useful enough in the hands of anyone who will take the trouble to understand it.

But still it does not reach our ideal of an easily read instrument suitable for the general public.

The chief point about this hygrometer is its accuracy. With careful observation, there is not much room for error, and in the good days when every member of the public shall possess his own hygrometer, this one should be kept by all Opticians for the purpose of testing and adjusting the popular instrument.

The next hygrometer which I have to describe is the so-called Mason's, or wet and dry bulb thermometer.

This hygrometer is the instrument which we, in England, generally associate with the name. It is based upon two physical laws :

1. That the rate of evaporation from a surface of water is inversely proportional to the percentage of saturation of the air in contact with it, and
2. That the act of evaporation entails an expenditure of heat proportionate to its rate.

The observation consists of reading the temperature of the dry thermometer, and the temperature of this other one, whose bulb is covered with muslin, which is kept constantly moist by means of a wick leading from a supply of water. If we call these two readings t and t' we can deduce the dew point from the following formula :

$$e = e' - .0009739 \ t' (t - t') - .5941 (t - t') \\ - .0008 (t \cdot t') (b - 755)$$

where e = elastic force of vapour.

e' = *e.f.v.* at t'

b = barometer height in millimeters,

and from the dew point we get as before the other hygrometric conditions.

These calculations have been made and are available to us in Glaisher's tables for all temperatures between 10° and 100° F. and for differences up to 24° . So that with the two thermometers and with a book of tables we can fairly easily arrive at the hygrometric conditions.

This is the instrument upon which we have mainly relied for the past 50 years to introduce the science of hygrometry to the general public; and that the result has been so poor is due, I contend, to the unsuitable nature of the instrument. When you have educated your average man to the point of reading a scale, as in a thermometer or barometer, you have pretty well reached

the limit of his capacity. To ask him to take two readings, and to compare them with a table of values, is to make a demand upon his powers of concentration altogether too severe.

But this difficulty of reading is not the only point against the Mason's hygrometer. To get correct results the instrument requires considerable care and attention; sources of error are many and fruitful.

1. The two thermometers must exactly correspond, not only at the points, but throughout the scale.
2. The muslin must cover the tube equally and entirely. A thick fold, a gap, a tear, dirt, or any other obstruction to the rapid absorption and evaporation of the water will interfere with the result.
3. The water must be absolutely pure.
4. The thermometer must be kept in a position where there is naturally or artificially a rapid current of air. This is most important, and most often overlooked. In stagnant air the layer of air surrounding the wet bulb becomes overladen with vapour, and the proper rate of evaporation is not maintained.

These possible defects, except perhaps 1, all tend the same way, *i.e.*, in the direction of lessening the difference between the two readings; so that, perhaps, after all, there is some excuse for the general public for having for so long looked askance at the Mason's hygrometer.

Where, then, are we to look for our popular hygrometer? You will recollect that I laid it down as one of the objects of this paper to indicate some simpler and more acceptable form of instrument than that which I have just described, and my suggestion is that we should revert to an older form of instrument which in this country, at any rate, we have practically lost sight of. It has long been known that human hair, properly selected and prepared, varies in length with the relative humidity of the air to which it is exposed. It has been found by experiment that when removed from dry to saturated air it increases consistently by $\frac{3}{128}$ or $\frac{1}{40}$ of its length. A hair hygrometer is no new instrument. I can recollect, when I was in Germany 25 years ago, seeing several instruments of this type in public places. It is described by Mr. R. H. Scott in the 1883 edition of his book on

"Meteorology," where he says: "I have described at some length the principle of the hair hygrometer, as although it is seldom used in this country it affords practically the most satisfactory means of determining the hygrometrical conditions of the air at temperatures close to and below the freezing point, under which circumstances the wet and dry bulb hygrometer fails." The chief advantage of the hair hygrometer, from my point of view, is that it allows of a scale from which can be read directly, by means of a pointer, the relative humidity of the air; which, for nearly all conceivable hygienic and domestic purposes, is what we want to know.

Its only drawback was its fragility. As I recollect the instrument, and as Mr. Scott describes it, it was constructed of a single hair. But this disadvantage has been effectually met in the instrument which I am showing you to-night. Here is a hair hygrometer made by Lambrecht in Göttingen, of a type which I believe is now widely used in Germany and Russia. Instead of the single hair we have here about twenty, with a result that the strength of the instrument is increased twenty fold.

There are other points in this hygrometer which evidence careful thought and great ingenuity. I would call your attention to the arrangements for adjusting it; the screw at the top corrects the position of the pointer (as we may set the hands of a watch). The nut at the bottom regulates the movement of the pointer relative to the scale (answering to the regulation of a watch). The scale on the dial gives the relative humidity, which you read off directly.

The thermometer is divided, as I have before suggested, with the degrees of temperature on one side, and the equivalent *e.f.v.* on the other. This enables you to find the actual vapour force present in the air by multiplying the amount of force shown on the right hand scale by the percentage of humidity shown on the dial, and dividing by 100. The actual vapour force being thus found, the dew point will be the degree of temperature opposite this reading. But in case this calculation should be too abstruse for the observer, a most ingenious device is provided by the constructor of the instrument. The number of degrees of difference between the dew point and the temperature of the air at different ratios of saturation is recorded upon an upper scale on the dial. So that to find the dew point it is only necessary to deduct the

number indicated upon the upper scale of the dial from the actual degree of temperature of the air. As this number of degrees of difference varies not only with the relative humidity, but also to a slight extent with the temperature, a further correction must be made, if an exact result is required; and to make this correction quite simple a further very ingenious device is adopted. You will notice that the end of the pointer is in the form of a trident, and on the scale at the base of the pointer is a similar trident with a figure 10 at its centre barb, a zero on the right, and a 20 on the left. According to the temperature you take your reading upon the centre right or left barb, or at an intermediate point.

I have ventured to demonstrate this instrument at some length, because of all the hygrometers I have recently seen, it seems to me to come closest to the ideal of an instrument adapted to the general public. Its chief virtue in this respect is the simplicity with which the relative humidity may be read; while at the same time other hygrometric conditions may easily be calculated by those who desire them.

I have left myself but little time to deal with the most important part of my paper—the application of hygrometry to practical purposes—and I shall not attempt on the present occasion to deal at all fully with the many ramifications of so extensive and complicated a subject. But I will ask you to bear with me a little longer while I try and indicate some of the more obvious uses to which hygrometric observations may be applied.

And I would group them roughly under three heads—

1. Hygienic.
2. Meteorological.
3. Technical.

And firstly with relation to hygiene; consider for a moment the effect of the hygrometric state of the air upon the physical condition of the body. From the skin a constant process of evaporation is taking place. The rate of this evaporation is entirely governed by the relative humidity of the air. Its effect upon the lungs is still more noticeable. With every inspiration nearly a pint of air is taken into the lungs; before its expulsion, this volume of air is heated and charged with vapour nearly to saturation point. So that a constant drying and cooling process is going on, for, of course, evaporation entails a loss of heat; and this process

again is entirely controlled by the hygrometric condition of the air, or, to be precise, by the position of the dew point.

We must all be conscious of the unpleasant effect of air that is too moist or too dry. Of the former variety we have sufficient experience in London. We call it by various names; we say it is heavy, 'muggy, oppressive, close. We vaguely attribute the unpleasant feelings it entails to the heat. But heat by itself is not unpleasant or injurious. I recollect some years ago a man telling me of an enjoyable cricket match played in Australia with a temperature of 123° F. in the shade. It is the combination of heat and moisture that is unpleasant and injurious.

On the other hand, air that is too dry is equally unhealthy. Our commonest experience of it is in an overheated room. Whatever there is of moisture in such a room is quickly dried up. The relative humidity falls, and the thirsty air attacks your skin and lungs. Evaporation is forced to its limit; notwithstanding the heat of the room, you feel cold; nervous irritability is induced, loss of appetite and insomnia.

Another experience of dry air is our old friend the east wind. Why does the east wind chill the marrow of your bones, penetrate the thickest clothing, and fill you with every variety of blue devils? Not because it is cold; a quite genial west wind is often much colder; but because it is dry. It desiccates your throat, it irritates your nerves, it dries and chills your lungs.

I should like to enlarge on the value of a hygrometer in choosing a house, in testing for dampness different rooms and cellars of a house, of the importance of hygrometric conditions in selecting a health resort, and especially of the use of hygrometry in the treatment of disease, and of the hygrometer in the sick-room. But time forbids; and I will conclude these desultory remarks on the hygienic aspect of hygrometry with these two rules of general application to healthy people.

1. The most favourable relative humidity lies between 60% and 75%. It should never fall below 40% or rise above 80%.
2. A dew point higher than 20° C. or 65° F. should be avoided.

In its application to the science of meteorology, the hygrometer is again of considerable interest and value. Apart from the

study of climatic conditions, it is a great help in the difficult problems connected with weather forecasting.

I take the following rules from Prof. Hans Hartl's "Einführung in die Wetterkunde" :

1. A rising dew point points to a proximate rise in temperature, a falling dew point to a fall in temperature.
2. A rapidly rising dew point (about 6° C. in 12 hours) foretells a distant thunderstorm and a dew point of 17° C. or higher points to the imminence of a local storm.
3. Strong variations of the dew point foretell heavy wind.
4. If the dew point fall below freezing point a night frost may be expected.

Further indications of approaching weather may be gathered by comparing the morning temperature, taken at 8 a.m., with the position of the dew point at 6 p.m.

1. If the evening dew point stand higher than the morning temperature a storm is threatened.
2. If the evening dew point is not more than 4° C lower than the morning temperature rain may be expected.
3. If the evening dew point is from 4° to 8° lower than the morning temperature there is promise of fine weather.
4. If the evening dew point is 9° or more below the morning temperature wind and short showers are indicated.

For technical purposes in not a few industries the hygrometer has also many applications. In horticulture for the prediction of rain, storm, hail, early frosts, etc., as also for the proper regulation of the moisture in hot houses; in the treatment of cotton in looms; in the manufacture of tobacco; in brewing, and in many other industries where the success of processes is dependent upon the hygrometric condition of the air a reliable instrument is required.

I cannot on the present occasion attempt an examination of all its possible uses, and I shall conclude by again commending to your very careful consideration this specimen of a hair hygrometer, and by asking you whether you do not consider that an instrument made upon somewhat similar lines would be acceptable to the general public, and would prove a source of interest and benefit to its owner, and of profit and satisfaction to the Optician.

DR. DRYSDALE said that although, as the lecturer had observed, the subject was in some respects an old one, it was of great interest. He would not hesitate to say that the instrument that had been particularly brought before their notice by Mr. Dixey came nearer to being a practical hygrometer, for the use of ordinary persons, than did any other. Many of those present were, no doubt, familiar with the usual instruments described in text books, but knew also of their imperfections. As Mr. Dixey had said, from the point of view of those practically interested in hygrometry the important thing was the relative humidity. Not one of the instruments to which he (the speaker) had referred just now gave this directly, and several of them were open to objection from a scientific point of view. With respect to the matter of adjustment, it was useless to expect the general public, or even people with a comparatively advanced knowledge of science, to do what the inventors and makers of instruments might themselves do readily. The corrections were made in a manner that was unique and very valuable, in the instrument brought forward by Mr. Dixey. Much might be added on the subject of the practical importance of hygrometry. For instance, the enormous influence that the condition of the air in this respect had on the cotton spinning industries might be mentioned. He believed that these industries were concentrated in the district surrounding Manchester, mainly because the hygro-metric conditions were there favourable.

MR. THORNTHWAITE said that the subject of hygrometry might be considered as, in a sense, closely connected with optics. He referred to the matter of optical definition. Everyone knew that if a speculum were exposed to cold, wet air, that would result in the deposition of a film of moisture upon it, which would prevent the attainment of optical definition. Under such circumstances, one must not bring the speculum into a warm room, to dry it off quickly, as that would cause damage to the silver film. While speaking of meteorology, he might refer to the recent lamented death of their old friend, Mr. Glaisher, a Fellow of the Royal Society, who was so very eminent a scientist, and whose son was equally distinguished in the special branch of mathematics. The life of the late Mr. Glaisher had illustrated the fact that the pursuit of science does not militate against longevity. His great adventures in the air, accompanied by the aeronaut,

Coxwell, would be within the knowledge of all present; and no doubt his painful experiences on his most memorable aerial voyage were connected not only with the coldness but also with the degree of humidity of the atmosphere. The speaker concluded by saying that he would like to be allowed to propose a hearty vote of thanks to Mr. Dixey for his most interesting paper.

MR. SUTCLIFFE rose to second this vote of thanks. He remarked that what he was about to say upon the subject might be deemed hardly scientific. Mr. Dixey had pointed out the applications of hygrometry in ordinary life. Mr. Thornthwaite had indicated the importance of the matter in relation to optics. He (the speaker), when he first heard of this lecture, had looked up the technical term in question in the dictionary—a not unusual course with most people. Subsequently he had the pleasure of meeting the lecturer, who said that it was to his regret he had chosen “a fearfully dry subject.” (Laughter.) Of course, added Mr. Sutcliffe, they would know what his answer to this was. (Laughter.) He had to confess that, until the lecture began, this comprised all that he knew about the subject. He was glad to be able to claim a better acquaintance with it now.

The vote of thanks having been put to the meeting, and carried *nem. con.*,

MR. DIXEY said that he was extremely obliged for the very kind way in which this vote had been put and received. Before adding a few further remarks, he would be glad to reply to any questions that might occur to anyone present.

A member said that he had come across the Lambrecht “Poly-meter,” and would like to know something of its relations to the Mason hygrometer, in respect of scientific accuracy.

MR. DIXEY said that the Lambrecht hair hygrometer, or poly-meter, as the designer called it, could not compare as regards accuracy with Mason’s instrument; but he (the speaker) thought the hair hygrometer very much more likely than the other to become popular. He considered that the hygrometric state of the air had really much more popular interest than the pressure of the air. Let them consider, for example, how a careful mother said, when the temperature was low and the air saturated with moisture. “It is too damp for the children to go out.” As the temperature rose and the relative humidity became lower, it was commonly understood that the tender skin and the lungs of

children might be more safely exposed. From the Optician's point of view, there should be an even better sale for hygrometers than for barometers. A popular scale could be easily devised for the former instrument, showing the moisture of the air, not necessarily by so technical a measure as that of percentage, but by a blue and a red division of the scale indicating healthy and unhealthy conditions respectively, which the merest housemaid could be taught to understand. Someone might say, while an over-heated room with low relative humidity is bad (for instance), of what use is this information? How should the observed condition be corrected? This was a large subject and one which time would not permit the speaker to discuss. He might say, however, that the relative humidity could be raised by lowering the temperature, as by opening the window. Or a spray of water dropping on to ferns or other foliage plants could be used. To lower the relative humidity was not so easy. Perhaps the best plan, where it could be carried out, was to make use of large blocks of ice on which the superfluous moisture should be permitted to condense and then run away—not to be allowed to remain exposed to the air of the room in a stagnant condition so as to undergo evaporation again and, in process of time, make the air as wet as before. With respect to what Mr. Thornthwaite had said, the deposition of moisture was a constant source of trouble to Opticians. All of them had to deal with this trouble in connection with spectacle lenses, trial lenses, opera glasses, and so on. If a customer took up an expensive pair of opera glasses, and found that he could see through them nothing much more than a typical "London fog," he was apt to think that the instrument was after all a bad one. In each of these cases, the remedy was simply to warm the offending glass. Again he thanked those present for the reception accorded to his paper.