

XXIV. *Description of a new Hygrometer:*
By Mr. John Smeaton, F. R. S.

Read March 21,
 1771. **H**AVING some years ago attempted to make an accurate and sensible hygrometer, by means of a hempen cord, of a very considerable length; I quickly found, that, though it was more than sufficiently susceptible of every change in the humidity of the atmosphere, yet the cord was, upon the whole, in a continual state of lengthening. Though this change was the greatest at first, yet it did not appear probable that any given time would bring it to a certainty; and futhermore it seemed, that, as the cord grew more determinate in mean length, the alteration by certain differences of moisture grew less. Now as, on considering wood, paper, catgut, &c. there did not appear to be a likelihood of finding any substance sufficiently sensible of differences of moisture, that would be unalterable under the same degrees thereof; this led me to consider of a construction which would readily admit of an adjustment; so that, though the cord whereby the instrument is actuated may be variable in itself, both as to absolute length, and difference of length under given degrees of moisture, yet that, on supposition of a material departure from its original scale, it might be readily re-
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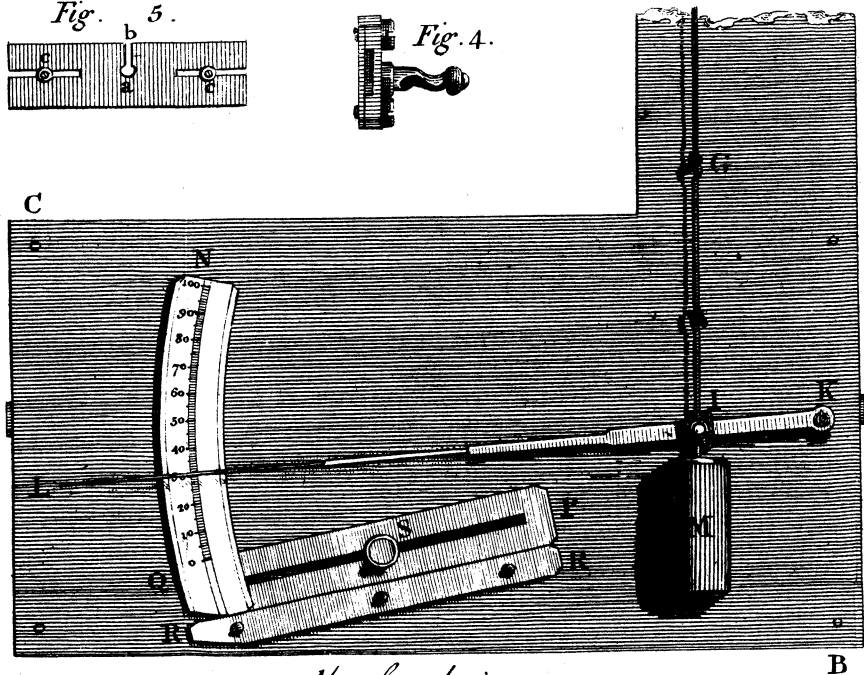
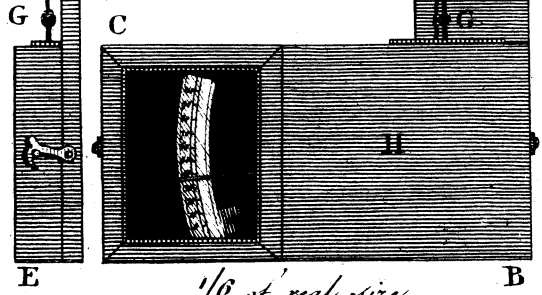
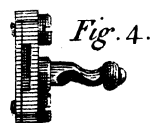
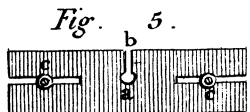
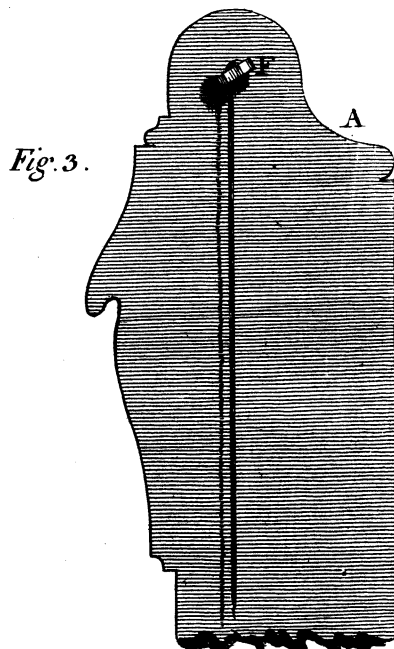
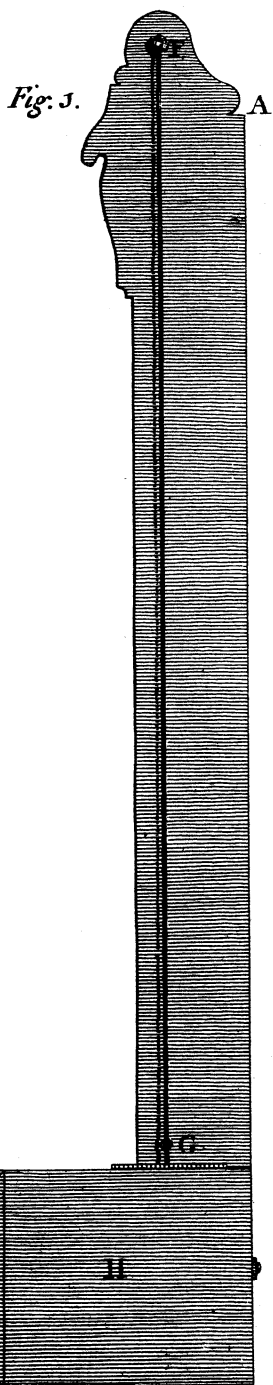
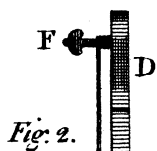
stored thereto, and in consequence that any numbers of hygrometers, similarly constructed, might, like thermometers, be capable of speaking the same language.

The two points of heat, the more readily determinable in a thermometer, are the points of freezing and boiling water. In like manner, to construct hygrometers which shall be capable of agreement, it is necessary to establish two different degrees of a moisture which shall be as fixed in themselves, and to which we can as readily and as often have recourse as possible. One point is given by making the substance perfectly wet, which seems sufficiently determinable; the other is that of perfect dry; but which I do not apprehend to be attainable with the same precision. A readiness to imbibe wet, so that the substance may be soon and fully saturated, and also a facility of parting with its moisture, on being exposed to the fire to dry; at the same time that neither immersion in water, nor a moderate exposition to the warmth of the fire, shall injure its texture; are properties requisite to the first mover of such an hygrometer, that in a manner exclude all substances that I am acquainted with, besides hempen and flaxen threads or cords, and what are compounded thereof.

Upon these ideas, in the year 1758 I constructed two hygrometers, as near alike as possible, in order that I might have the means of examining their agreement or disagreement on similar or dissimilar treatment. The interval or scale between dry and wet, I divided into 100 equal parts, which I call the degrees of this hygrometer. The point of 0 denotes

denotes perfect dry; and the numbers increase with the degrees of moisture to 100, which denotes perfect wet.

On comparing them for some time, when hung up near together in a passage or stair-case, where they would be very little affected by fire, and where they would be exposed to as free an air as possible in the inside of the house, I found that they generally were within one degree, and very rarely differed two degrees; but, as these comparisons necessarily took up some time, and were frequently interrupted by long avocations from home, it was some years before I could form a tolerable judgement upon them. One thing I soon observed, not altogether to my liking; which was, that the flaxen cords, which I made use of, seemed to make so much resistance to the entry of small degrees of moisture (such as is commonly experienced within doors in the situation above-mentioned) that all the changes were comprized within the first 30 degrees of the scale; but yet, on exposing them to the warm steam of a wash-house, the index quickly mounted to 100. I was therefore desirous of impregnating the cords with something of a saline nature, which should dispose them more forcibly to attract moisture; in order, that the index might, with the ordinary changes of moisture in the atmosphere, travel over a greater part of the scale of 100: how to do this in a regular and fixed quantity, was the subject of many experiments, and several years interrupted enquiry. At last, I tried the one here- after described, which seemed to answer my intentions in a great measure; and though, upon the whole, it does not ap-
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1/6 of real size.

1/3 of real size.

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pear likely that this instrument will ever be made capable of so accurate an agreement, as mercurial thermometers are made to be; yet, if we can reduce all the disagreements of an hygrometer within $\frac{1}{40}$ th part of the whole scale, it will probably be of use in some philosophical enquiries, in lieu of instruments which have not as yet been reduced to any common scale at all.

Description of the Hygrometer.

Fig. 1 and 2, A B C is an orthographick delineation of the whole instrument seen in front in its true proportion.

D E is that of the profile, or the instrument seen edgeways.

F G, in both, represents a flaxen cord, about 35 inches long, suspended by a turning peg F, and attached to a loop of brass wire at A, which goes down into the box cover H, which defends the index, &c. from injury, and by a glass exposes the scale to view.

Fig. 3. shews the instrument to a larger scale, the upright part being shortened, and the box cover removed; in which the same letters represent the same parts as in the preceding figures; G I are two loops or long links of brass wire, which lay hold of the index K L, moveable upon a small studd or center K. The cord F G is kept moderately strained by a weight M, of about half a pound avoirdupoise.

It is obvious, that as the cord lengthens and shortens, the extreme end of the index rises and falls, and successively passes over

N 2 the scale, disposed in the arch of a circle, and containing 100 equal divisions. This scale is attached to the brass sliding ruler Q P, which moves upon the directing piece R R, fixed by screws to the board, which makes the frame or base of the whole; and the scale and ruler, N Q P, is retained in any place, nearer to or further from the center K, as may be required, by the screw S.

Fig. 4. represents in profile, the sliding piece, and studd I. (fig. 3.), which traverses upon that part of the index next the center K; and which can, by the two screws of the studd, be retained upon any part of the index that is made parallel; and which is done for 3 or 4 inches from the center, for that purpose. The studd is filed to the edges, like the fulcrum of a scale beam, one being formed on the underside, the other upon the upper, and as near as may be to one another. An hook formed at the lower end of the wire loops C I, retains the index by the lowermost edge of the studd, while the weight M hangs by a small hook upon the upper edge: by these means the index is kept steady, and the cords strained by the weight, with very little friction or burthen upon the central studd K.

Fig. 5. is a parallelogram of plate brass, to keep out dust, which is attached to the upper edge of the box cover H, and serves to shut the part of the box cover necessarily cut away, to give leave for the wire G I to traverse with the sliding studd (fig. 4.) nearer to, or further from, the center of the index K; and where in (fig. 5.) *a* is an hole about $\frac{1}{3}$ of an inch diameter, for the wire G I to pass through, in the rising and falling of the index,
freely

freely without touching; *b* is a slit of a lesser size, sufficient to pass the wire, and admit the cover to come off without deranging the cord or index; *c c* are two small screws applied to two slits, by which the plate slides lengthways, in order to adapt the hole *a* to the wire G I, at any place of the fludd I upon the index K L.

Remarks on the preceding Construction.

1st. In this construction the index K L being 12 inches long, 4 inches from the extreme end are filed so narrow in the direction in which it is seen by the eye, that any part of these 4 inches, lying over the divisions of the scale, becomes an index thereto. The scale itself slides 4 inches, so as to be brought under any part of the 4 inches of the index, attenuated as before mentioned.

2dly. The position of the directing piece R R is so determined, as to be parallel to a right line drawn through the point *o* upon the scale, and the center K of the index; consequently, as the attenuated part of the index forms a part of a radius, or right line from the same center, it follows, that whenever the index points to *o* upon the scale, though the scale is moved nearer to or further from the center of the index, yet it produces no change in the place to which the index points.

3dly. When the divided arch of the scale is at 10 inches from the center (that is, at its mean distance) then the center of the arch and the center of the index are coincident. At other distances, the extremes of which are 8 or 12 inches, the center of

the divisions and center of the index, pointing thereto, not being coincident, the index cannot move over spaces *geometrically* proportionable to one another in all situations of the scale; yet, the whole scale not exceeding 30 degrees of a circle, it will be found on computation, that the error can never be so great as $\frac{1}{1000}$ th part of the scale, or 1 degree of the hygrometer; which in this instrument being considered as an indivisible, the mechanical error will not be sensible.

Choice and Preparation of the Cord.

The cord here made use of is of flax, and be-twixt $\frac{1}{20}$ th and $\frac{1}{30}$ th of an inch in diameter; which can readily be ascertained by measuring a number of turns made round a pencil or small stick. It is a sort of cord used in London for making nets, and is of that particular kind called by net makers *flaxen three threads laid*. I do not imagine that the fabrick of the cord is of the most material consequence; but yet I suppose, when cords can be had of similar fabrick, and nearly of the same size, that some small sources of variations will be avoided. In general I look upon it that cords, the more they are twisted, the more they vary by different degrees of moisture, and the less we are certain of their absolute length; therefore those moderately twisted, I suppose, are likely to answer best.

A competent quantity of this cord was boiled in one pound avoirdupoise of water, in which was put two pennyweights troy of common salt; the whole was reduced by boiling to 6 $\frac{2}{3}$ avoirdupoise, which

was done in about half an hour. As this ascertains a given strength of brine on taking out the cord; it may be supposed that every fibre of the cord is equally impregnated with salt. The cord being dried, it will be proper to stretch it; which may be done so as to prevent it from untwisting, by tying three or four yards to two nails, against a wall, in an horizontal position, and hanging a weight of a pound or two to the middle, so as to make it form an obtuse angle. This done for a week or more in a room, will lay the fibres of the cord close together, and prevent its stretching so fast after being applied to the instrument, as it otherwise would be apt to do.

I have mentioned the sizes and principal dimensions that I have used; as the instruments may as well be similarly constructed as otherways; but I do not apprehend it to be very material to agree in any thing but the strength of the brine on taking the cord out of it. If the cord is adapted to the instrument some days before its first adjustment, I apprehend it will be the more settled.

Adjustment of the Hygrometer.

The box cover being taken off, to prevent its being spoiled by fire, and chusing a day naturally dry, set the instrument nearly upright, about a yard from a moderate fire; so that the cord may become dry, and the instrument warm, but not so near as would spoil the finest linen by too much heat, and yet fully evaporate the moisture; there let the instrument stay, till the index is got as low as it will go,
 now

now and then stroking the cord betwixt the thumb and finger downwards, in order to lay the fibres thereof close together, and thereby causing it to lengthen as much as possible: when the index is thus become stationary, which will generally happen in about an hour (more or less as the air is naturally more or less dry), by means of the peg at top raise or depress the index, till it lays over the point *o*; this done, remove the instrument from the fire, and having ready some warm water in a teacup, take a middling camel's hair pencil; and dipping it in the water, gently anoint the cord, till it will drink up no more, and till the index becomes stationary, and water will no more have effect upon it; which will also generally happen in about an hour. If in this state the index lays over the degree marked 100, all is right: if not, slack the screw *S*, and slide the scale nearer to or further from the center, till the point 100 comes under the index, and then the instrument is adjusted for use: but, if the compass of the slide is not sufficient to effect this, as may probably happen on the first adjustment, slack the proper screws, and move the sliding studd *I* nearer to or further from the center of the index, according as the angle formed by the index, between the points of dry and wet, happeneth to be too small or too large for the scale; the quantity can easily be judged of, so as the next time to come within the compass of the slide of the scale; the quantity of slide being $\frac{1}{3}$ of the length of the index, and consequently its compass of adjustment $\frac{1}{3}$ of the whole variable quantity. Now as sliding the studd *I* will vary the position of the index

dex respecting the point of *o*, this movement is only to be considered as a rough or preparatory adjustment, to bring it within the compass of the slide of the scale; which will not often happen to be necessary after the first time; but in this case, the adjustment must be repeated in the same manner, by drying and wetting as before described.

It is to be remarked, that, as the cord is supposed impregnated in a given degree with common salt, and this not liable to evaporate, care must be taken in wetting, that no drops of wet be suffered to fall from the cord: for, by the observance hereof, the original quantity is preserved in the cord.

Observations made upon two original Hygrometers.

These hygrometers were first adjusted, after the impregnation of the cords with common salt, in February 1770; they were kept together in a staircase till the summer following; they were frequently observed, and rarely found to differ more than one degree.

In summer, one of them remaining in the former place, the other was removed into a passage through a building; which having no doors, and the instrument being hung so that neither rain nor the direct rays of the sun could fall upon it, thereby it became exposed to the winds, and the free passage of the open air. In these situations the two hygrometers not only differed very greatly in quantity, but even frequently were moving different ways. They were thus continued till January 1771, in which space of time I observed, that the most ordinary place of the
index

index was between 15° and 25° in the open air; that at 40° the atmosphere felt very sensibly moist; but yet it was frequently above 60° ; and more than once at 70° , or very near. I have therefore marked the point of 0 *dry*; 20° the *mean*, 40° *moist*, 70° *very moist*, 100° *wet*. I do not, however, mean those words (that of dry and wet excepted) as of any other intent, than that of general direction, in like manner as those upon the barometer; leaving the relative degrees of moisture to be judged of by the scale.

In the month of January last, I restored the exposed hygrometer to its former place in the staircase, when both instruments were again compared together; and they rarely differed more than 1 degree, and never so much as 2° . After this, they were both removed together to the out passage; and there they agreed nearly in the same manner, the utmost difference not exceeding 2 degrees. After some trial here, one of them was readjusted, leaving the other hanging in its place. On restoring the new adjusted instrument to the other, they now differed about 5° , the new adjusted one standing so much higher. The day following the other was readjusted also, and afterwards restored to its place with the former, which had been left in the out passage; and after this readjustment they both agreed to 1° . This being observed for some days, one of them was taken down, in order to be packed up for London; this I have now the honour of exhibiting to the Royal Society; and I beg to leave it in the Society's house, that in case any one should be desirous

desirous of having an instrument made on the same plan, they may have recourse thereto.

It appears from the foregoing observations, that, in the compass of 11 months, the cords had stretched the value of 5° : and I also observed that they both had contracted their compass about 10° . I would, therefore recommend, that an hygrometer should from its first adjustment, be readjusted at the end of three months, and again, at the end of six months from the first; after that, at the interval of about six months, to the end of two years from the beginning; and after that, I apprehend that once a year will suffice; the best time of adjustment, being in the dry and warm weather of July or August: and by these means, I apprehend the instrument will be always kept within 2° of its proper point.

Respecting the sensibility of this instrument, it has that in a greater degree than its constancy to its scale can be depended upon, which was all that I intended; where greater degrees of sensibility are required, to make comparisons at small intervals of time, the beard of a wild oat, and other constructions may be used, with advantage; this instrument being considered as a cheque upon them as to more distant periods.

General Conclusion.

I am aware that an hygrometer actuated by any principle of the kind here made use of may not be a measurer of the quantity of moisture, actually dissolved in, and intimately mixed, with the air; but only indicates the disposition of the air to part with,

or precipitate the water contained in its substance; or, on the contrary, to dissolve and imbibe a greater quantity: but as it is by separating the effects of natural causes, that we are enabled to judge of these causes, and from thence their effects when again compounded; every attempt to ascertain the operations of a simple cause will have its value in the search into nature: nor can we *a priori* determine the value of any new instrument; for, if it should lead to a single discovery, or even to ascertain a single fact, this may again lead to others of great importance, of which we might have, either none, or an imperfect idea of before. For my own part, I have always looked on a thick fog, and the sweating, or condensation of the water's vapours upon the walls in the inside of buildings, to be the greatest marks of a moist atmosphere: whereas I have not always found the hygrometer affected at these times in the highest degree. On the contrary at the close of a fine day, and the fall of the dew on the sudden approach of a frost, I have found the hygrometer more affected by moisture than in some of the preceding cases; and still more by a falling dew in the time of an hard frost. I just mention these matters of hints for the enquiry of others; not having had length of time, since I brought the instrument to answer my intention, to make any absolute conclusions.

I am sorry I have been obliged to take so much compass, to describe and explain a very simple instrument; but as I meant at the same time to give some idea of what is to be expected from it, I thought
it

it more excusable to be prolix than not sufficiently explicit.

London,
March 21, 1771.

J. Smeaton.

P. S. It is to be noted, that, after each readjustment, though the hygrometers would generally within a few hours come near their point, yet it was not till the next day that they could be depended on, as having come to their nearest agreement.