July 6, 1954 J. W. CASE 2,682,858

WOOD MEMBRANE HYGROMETER

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FIG. 1

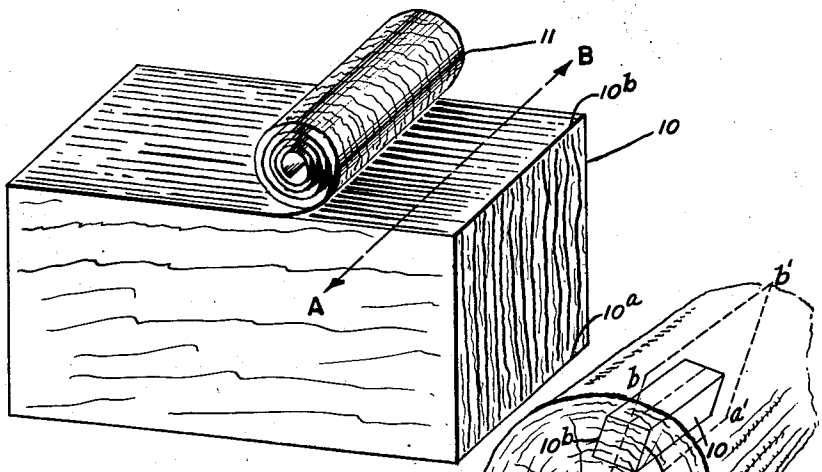


FIG. 1A

FIG. 2

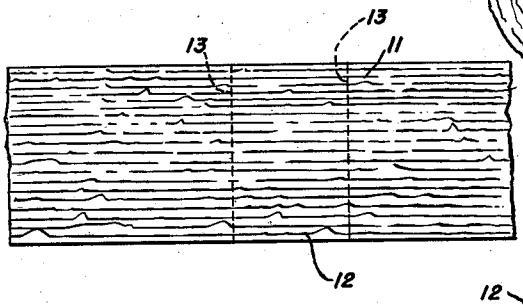
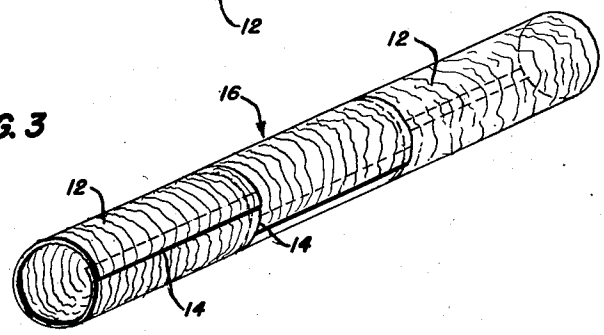


FIG. 3



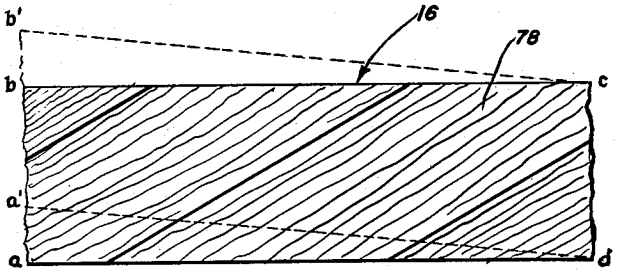


FIG. 4

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WOOD MEMBRANE HYGROMETER

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FIG. 5

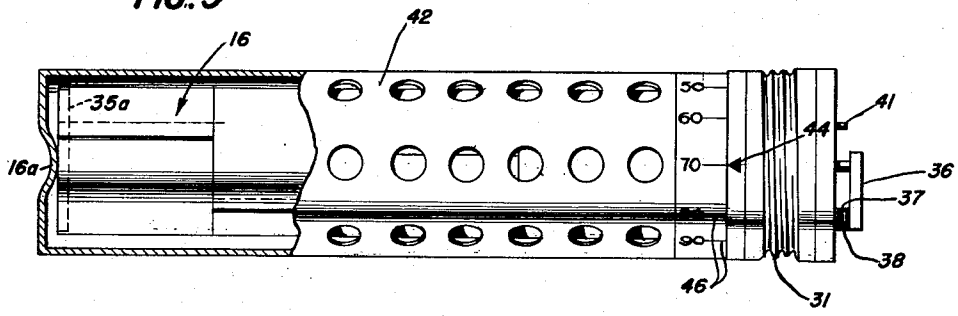


FIG. 6

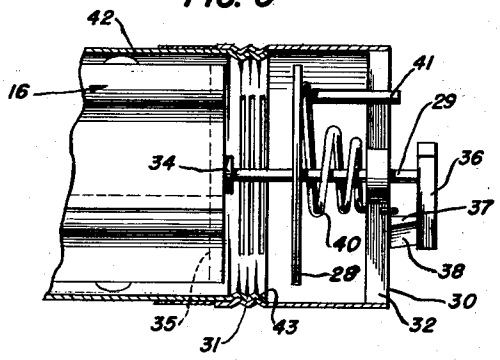


FIG. 7

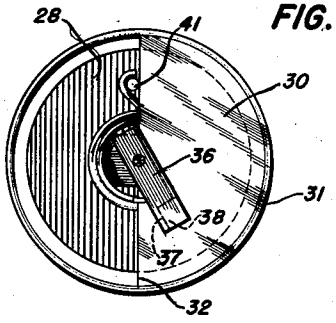


FIG. 10

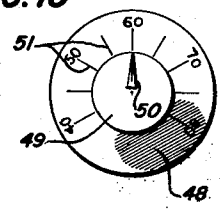
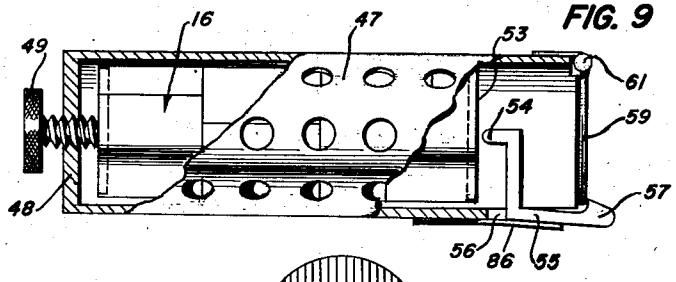


FIG. 9



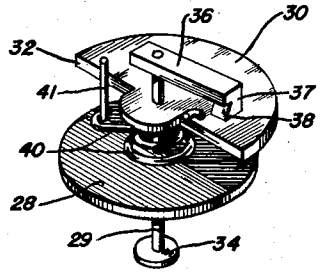


FIG. 8

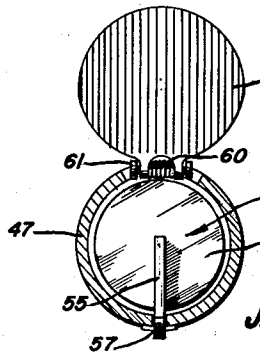


FIG. 11

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Patented July 6, 1954 2,682,858

UNITED STATES PATENT OFFICE

2,682,858

WOOD MEMBRANE HYGROMETER

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Application December 13, 1951, Serial No. 261,570

7 Claims. (Cl. 116—114)

(Granted under Title 35, U. S. Code (1952), sec. 266)

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This invention relates to improvements in hygrometers, and more particularly relates to devices for determining the relative amount of moisture in the atmosphere by means of thin wood membrane sensitive elements.

The purpose of this invention is to provide an inexpensive, accurate, rugged instrument which can be relied upon for visual indication of the relative humidity inside of packages, containers, shipping cases, igloos, buildings, etc., in which perishable material is shipped or stored in a dehumidified atmosphere as a means of preservation.

The technique of preserving perishable equipment by means of dehumidified air was developed during and succeeding World War II, when it was found by numerous investigators that rusting and corrosion of metals is greatly reduced in an atmosphere below 50% relative humidity; that positive protection against rust and corrosion is obtained in air below 30% relative humidity and that most forms of mildew are prevented from growing below 70% relative humidity. These discoveries led to the development of standardized procedures for dry air preservation which are being widely practiced by the military services and commercial contractors.

Essentially, the procedure consists of enclosing the material or equipment being preserved in a moisture vapor barrier with silica-gel, which takes the moisture out of the enclosed air space, either by static adsorption or by stripping the moisture from the air which is circulated through the silica-gel bed by mechanical means.

Since the moisture vapor barriers of such enclosures permit a continual small leakage of moisture from the outer atmosphere into the enclosures, some means of occasionally checking the moisture quality of the enclosed atmosphere is a necessary adjunct to this preservation process, thereby to inform maintenance and inspection personnel whether or not the atmosphere of the enclosure is below the safe upper critical limit of relative humidity and assure adequate protection of the material under preservation.

Presently available means for the indication of the relative humidity in dehumidified shipping packages and containers are inadequate because they are either too costly and cumbersome, or because they are not accurate within the critical values of moisture which must not be exceeded.

One conventional means utilizes cobalt-chloride impregnated silica-gel to indicate the moisture condition of the container atmosphere by certain characteristic colors, depending upon the atmospheric relative humidity at which the silica-gel is in moisture equilibrium. This indicating means is not only limited to a qualitative indication of the moisture in the air, but is also subject to false indication, due to its gradual accumulation of moisture with each daily peak of relative humidity (caused by atmospheric temperature change in the container). This false indication results in unnecessary expense in the opening of the enclosure to inspect the contents, renew the silica-gel charge, etc.

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Another available means employs mechanical hygrometers having sensitive elements of human hair, animal membrane, paper-metal laminate, etc. While such instruments give considerably more accurate indication of the relative humidity than the silica-gel indicators above described, they have not been generally adopted for use in shipping and storage packages, because they are too expensive in comparison with the value of material in the individual containers or packages; lack the desirable compactness for adaptation; are subject to accumulative scale errors due to aging effects on their sensitive elements and are in general too frail to withstand the shock and vibration to which packages and containers are subjected during shipment.

The present invention contemplates the use of the hygroscopicity of wood and more particularly, the distortional characteristics of thin wood membranes in moisture equilibrium with the atmosphere as moisture sensitive elements in low-cost, compact, reliable hygrometers, humidity indicating devices, controllers, etc.

The constants of the characteristic deformation of various species of wood with changes of moisture content have been well established during the practice of kiln drying of lumber by the lumber industry and in research carried out by the Forest Products Laboratory of the U. S. Department of Agriculture. To quote the latter authority:

"Wood shrinks most in the direction of the annual growth rings (tangentially), about one-half as much as this across these rings (radially) and very little, as a rule, along the grain (longitudinally)". . . . "The shrinkage that occurs when the moisture content is reduced below the fiber-saturation point is basically dependent upon the amount of moisture removed from the cell walls." . . . "For practical purposes, swelling may be considered the reverse of shrinkage." . . . "For purposes of calculating shrinkage, or swelling, the moisture content-shrinkage relationship may be considered a direct one."

For reasons which are explained later, the

selection of the radial shrinkage and swelling of wood are characteristics which can be depended upon for accurate indication of the amount of moisture in the atmosphere by means of thin wood membranes. Further, there have been selected species of wood which are durable; which are easily worked and which have sufficient moisture-distortion gradients for actuation of indicating means in mechanical hygrometers. For example, the unit radial distortion of three typical species of wood, over the full range of relative humidity are calculated from Forest Products Laboratory data and are indicated in the following table.

Unit radial distortion of wood in moisture equilibrium at various relative humidities and 70° F. (DB).

R. H.	Moisture Content, Percent	Length, Inches		
		Eastern White Pine	Yellow Poplar	Hickory
100	31	1.000	1.000	1.000
90	20.8	.9925	.987	.976
80	16	.988	.98	.964
70	13	.986	.977	.9575
60	10.9	.984	.974	.9525
50	9.1	.983	.972	.948
40	7.6	.982	.969	.944
30	6	.981	.9675	.940
20	4.5	.980	.966	.937
10	2.5	.979	.963	.9325

It has been found that the moisture distortion characteristics of wood, above cited, are not useful for the moving force in a mechanical hygrometer in a thick section cut from the tree, as in a piece of lumber, but the sensitive element must be made in a very thin membrane which can rapidly respond to changes of the atmospheric moisture. According to the literature, wood was one of the first materials utilized in the construction of hygrometer sensitive elements. However, all types of wood sensitive elements employed by previous inventors are of relatively thick sections, in which an appreciable time is required for equal wetting of the mass and swelling of the internal fibers. This circumstance causes objectionable time lag between changes of atmospheric moisture and the desired dimensional change of the sensitive element. The inherent time lag and sluggish nature of wood sensitive elements employed by previous inventors has generally prevented the use of this type of element in commercial hygrometers which normally employ human hair, animal membrane, paper-metal laminate, etc. as sensitive elements. It has been found, further, that all such organic fibers have an inherent time lag of at least 40 minutes between changes of relative humidity and that, for comparable performance, a wood fiber must be of approximately the same thin section, or at least, as thin as practicable within the limits of the mechanical factors incident to the service of the instrument.

There has therefore been produced a wood hygrometer sensitive element of comparable thinness, accuracy and sensitivity to other organic fibers which are employed in hygrometers.

From those statements it will be understood that one of the objects of the invention is to provide an improved moisture indicating instrument for the guidance of shippers and inspection personnel who are charged with the safe transit or storage of valuable equipment which is subject to rusting, corrosion and mildew and which is preserved by means of moisture vapor barriers and dry air.

Another object of the invention is to provide a moisture indicating device which is contrived to give warning, by means of a visual mechanical signal, when the critical value of relative humidity in dehumidified shipping packages or containers is reached.

Another object of the invention is to provide moisture sensitive elements of thin wood membranes for hygrometers and hygrosignals.

Another object of the invention is to provide moisture sensitive elements for hygrometers and hygrosignals which are resistant to the effects of solvent vapors, such as methyl-ethyl-keytone, ethyl alcohol, and petroleum solvent which are commonly used in moisture barriers and in metal preservatives.

Another object of the invention is to provide moisture sensitive elements for hygrometers which will have uniform moisture-distortion characteristics when produced in quantity, so that the hygrometers in which they are used may have duplicate scales and will assure acceptable accuracy over the full range of relative humidity.

Another object of the invention is to provide simplified mechanical magnification means for hygrometer sensitive elements to eliminate accumulative instrument errors due to strain on the elements and shock or vibration during service.

Another object of the invention is to provide a tripping and resetting means for a mechanical signal which are operated at preset values of relative humidity by moisture sensitive elements.

Another object of the invention is to provide moisture sensitive elements which are responsive with a minimum of lag to the fluctuating moisture vapor conditions in the atmosphere.

Another object of the invention is to utilize the steps of a method of producing the critical membraneous-wood tube which is the sensitive element of the hygrometer.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

Fig. 1 is a perspective view illustrating the first mechanical step of the method of producing the sensitive element;

Fig. 1A is a diagrammatic perspective view showing the method of cutting a block from a log preparatory to obtaining a wood membrane which is expansive and contractive radially in the tree;

Fig. 2 is a plan view of the membraneous-wood shaving, stretched out preparatory to cutting;

Fig. 3 is a perspective view of a tube wherein the membraneous wood sections are joined for rectilinear expansion and contraction;

Fig. 4 is a diagram illustrating a development of a spiral winding of the wood membrane for rotational expansion and contraction;

Fig. 5 is a side elevation, partly in section, of a modification of the hygrometer of the immediately preceding type employing a trippable signal flag;

Fig. 6 is an enlarged section of the trip end of the latter hygrometer;

Fig. 7 is an elevation of the hygrometer in Fig. 7, showing the trigger and flag in the unset position;

Fig. 8 is a detail perspective view, particularly showing the undercut of the trigger;

Fig. 9 is a partially elevational and sectional view of a modification of the hygrometer in Fig. 6;

Fig. 10 is an elevation of one end of the hygrometer in Fig. 9;

Fig. 11 is an elevation of the other end of the hygrometer in Fig. 9;

The method of making the sensitive element is described first, then its applications. In Fig. 1, **10** designates a block of close-grained, well seasoned soft wood. Species that are regarded as suitable for the instant purpose include White Pine (*Pinus strobus*), Yellow Poplar (*Liriodendron tulipifera*) and Red Cedar (*Juniperus virginiana*). The block **10**, Fig. 1, is cut from a log **9**, Fig. 1A, according to the common commercial practice of "quarter sawing" to bring out the radial grain of the wood. As shown in Fig. 1A, the block **10** is cut from the timber so that the faces **10***a*, **10***b* of the block are purposely in parallel orientation with the radial plane *aa'bb'*. Now when a shaving is cut from the face **10***b*, Fig. 1, in the direction of the grain and across the ring growth laminations, there is produced a thin membrane **11**, Fig. 2, which utilizes only the radially distortional constants of the wood along the line A—B, Fig. 1. This manner of cutting the block insures a uniformity of distortion in the active element of the hygrometer which could not be obtained in any other known way. It is this uniformity of distortion which is responsible for the manner of response of the hygrometer element to ambient moisture as set out herein. The desired specimen having been selected, a shaving **11** is cut from one side in the manner described above.

A sharp carpenter's plane is used for this purpose, or any equivalent instrument that will produce a uniform, unbroken shaving from .0035 of an inch to .005 of an inch thick. The width of the block, hence of the shaving, is about 1⅜ inches. Much wider shavings could be produced with proper tools. This would avoid the necessity for piecing as below, and would make possible a sensitive element in one piece. The shaving thus produced is quite flimsy and has but little strength across its width. Consequently, care has to be taken in the next step of smoothing the shaving out as in Fig. 2 and cutting from it sections **12** of uniform length. The cuts are made along the lines **13**.

These sections **12** are assembled on a mandrel (not shown) and united at the joints **14** with an alkyd resin, cellulose nitrate, or phenolic cement, available commercially. The longitudinal joints are desirably staggered around the mandrel. The result is the cylinder **16** in which the joints furnish reinforcement to the otherwise frail sections. This cylinder is the sensitive element. Now, since the sections **12** are assembled end on end with their axes corresponding, in the tree, to the radial plane *aa'bb'*, Fig. 1A and the line A—B Fig. 1, the cylinder **16**, Fig. 3, forms a moisture-sensitive element which is responsive only to the radially expansive constant of the tree wood. When the humidity is on the increase the cylinder will expand lengthwise and as the moisture content diminishes the cylinder will contract. Tests to date show that a maximum dimensional change of an element as shown in Fig. 3 when made of White Pine is on the order of .002 inch per inch length.

The modification in Fig. 5 has the trippable flag **28** (Figs. 6 and 7) for the signal or indicating element. This flag is a disk, one half of which is painted red, the other half green or some optionally contrasting colors. The disk is fixed on a spindle **29** which becomes a push pin. The push pin is slidably carried by the cover **30** of the screw cap **31** which is cut away as at **32** (Fig. 7) to provide a window and a bearing for the push pin.

A pad **34** at the inner end of the push pin confronts a plug **35** in the near end of the membranous sensitive element **16**. The opposite end of the element has a plug **35***a* resting against a boss **16***a* which forms a mounting in the bottom of the tube **42**. The outer end of the pin **29** carries a trigger **36** the free end of which is angled downwardly at **37** to engage the edge of the cut-away **32** to hold the trigger in set position. The angled end is desirably undercut at **38** to insure a sharp edge for contact with the equally sharp edge of the cut-away **32**. A counterclockwise turn of the trigger **36** from the unset position in Fig. 7 registers the sharp edge of the end **37** with the cut-away whereupon the trigger is caught and held.

The spring **40** functions in the setting of the trigger and in its return to the unset position (Fig. 7). It is coiled around the spindle **29**; one end is fastened to the cover **30**, the other and free end is anchored to a stop pin **41**. In practice the coil of the spring exercises a degree of axial expansion and a consequent endwise pressure. This both keeps the pad **34** in contact with the plug **35** only at times, however, and causes the knife-edge of **37** to spring out of engagement with the cut-away **32**. The pin **41** is fixed in the flag **28**, stands erect therefrom and strikes the edge of the cut-away **32** when the trigger is in the unset position.

The outer, perforated metal tube **42** which forms the casing for most of the hygrometer in Fig. 5, has a thread course **43** (it is much like a flashlight casing) onto which the cap **31** is screwed. A scriber or similar mark **44** on the screw cap is readable against the graduations **46** on the tube and thus a setting of the hygrometer for a chosen humidity condition is made. Assume, for example, that an 80% ambient humidity is determined upon for the signaling of the flag **28**. The cap is turned until the hygrometer shows that reading.

It depends on the moisture content of the sensitive element **16** whether or not the pad **34** will touch. On the assumption that the ambient humidity was less than 80% the pad will stop short of the plug **35**, as shown. Now, as the sensitive element takes on moisture, it expands axially and at the designated time pushes the knife edge **37** off of the edge of the cut-away **32**. The spring **40** then takes over, swinging the flag from its set (green) position to the danger (red) position Fig. 7.

If the moisture content of the sensitive element happened to be more than corresponded to an ambient humidity of 80% it would not have been possible to adjust the cap **31** to the stated setting. The plug **35** would be supporting the spindle **29** and trigger **36** at an elevation so that the knife-edge **37** could not catch the edge of the cut-away even if swung into registration with it. If the ambient humidity were less than the chosen 80%, all of the foregoing collateral mechanical conditions would be reversed. Consequently the trigger would set and stay set until an 80% humidity condition was reached.

Figs. 9, 10 and 11 illustrate a modification of the structure in Fig. 5. Each has a trigger-held and released flag and in that respect they are, broadly, alike. The distinction is that in Fig. 5 both the flag and trigger turn in the same direction on the axis of the hygrometer in pursuance of the release of the trigger upon the axial elongation of the sensitive element by the accretion of moisture, whereas in Fig. 9 both the flag and trigger swing laterally and in opposite directions when the trigger is released in response to said elongation. The perforated metal tube **47** now has a closure **48** for one end, made either thick enough or formed otherwise to support a thread course for the screw stem of a knurled, humidity-setting nut **49** which then becomes a mount for one end of the sensitive element.

To the latter end the nut **49** (Fig. 10) has a scriber or equivalent mark **50** which is registrable with the graduations **51**, numbered in percentages of humidity, as said nut is turned. This turning adjusts the support of the sensitive element **16** on the inside of the tube. As in Fig. 5, the ends of the element are plugged, the plug **53** in the end opposite to closure **48** being in more or less close but operative proximity to the pad **54** of the trigger **55**.

Said trigger is pivoted in a slot **56** extending through to the open end of the tube and has a sharp-edged angled end **57** and a spring **86**, to hold the angled end **57** in engagement in the set position. The angled end **57** is engageable with the equally sharp edge of the flag **59** which, like the flag **28** in Figs. 6 and 7 is painted red and green; red on the inner surface, green on the outer surface. When the hygrometer is set as in Fig. 9 the flag shows green. When the flag is tripped as in Fig. 11 it shows red.

A spring **60** is so assembled on the pivot spindle **61** of the flag as to urge the flag up to the signaling position when released by the trigger. In actual practice, the hygrometer in Fig. 9 is capable of being made in a form much on the order of a pencil, that is to say, long and slender. This facility adapts it to purposes for which the form in Fig. 5 may prove not as well suited. But either of these two types is well adapted to embodiment in packages of equipment which is to be guarded against an excess of humidity. They are intended to be so mounted that the signal flag is visible through a glazed window in the package.

Fig. 4 illustrates the first and only modification of the sensitive element itself. Here, instead of being made in sectional form the shaving in Fig. 1 is left intact and is formed into a unitary wood shaving **18**, spirally wound into a tubular element and made to remain so by spots of cement at intervals. The purpose is accomplished, for example, by winding the shaving spirally on a $\frac{1}{16}$'' mandrel and lightly cementing the edges at points about ½'' apart with cellulose nitrate, alkyd resin or phenolic cement.

The object of this is to produce a non-rigid tube which will permit respective rotation between the two opposite ends, due to spiral distortion upon the accretion and loss of moisture. It has been found that such a tube 6'' long will rotate approximately 30° between opposite ends from ambient conditions of between 50% and 100% relative humidity.

In further explanation of Fig. 4, the rotative effort caused by the expansion (or contraction) of the wood membrane will be understood from the development of the spirally wound element. In accordance with the transverse grain expansion set out before, the maximum dimensional change of the developed sheet is diagonally between points *b* and *d*. This represents a distortion of the rectangular sheet into a parallelogram as shown at *a'b'cd*. With points *cd* fixed, as they will be by the cementing down of the tube, the movement of points *ab* to *a'b'* corresponds to clockwise motion at the free end of the tube, in other words to an extent where the element is in equilibrium with the particular moisture content of the ambient air.

The operation of the various forms of the hygrometer is generalized thus: The accretion or loss of moisture by the wood-membrane sensitive element **16** causes a dimensional change therein which is utilized to shift the indicating needle. This occurs either by axial elongation or contraction or by the twisting of the tubular body. The humidity indicator (flag or needle) is moved by spring-trigger action (Figs. 5 and 9).

The invention described herein may be manufactured and used by and for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed is:

1. In a hygrometer, a moisture sensitive element consisting of a tubular membrane, a casing in which said element is contained, mounting means in the casing for one end of the element the other end of the element being free to move, a spring-loaded signal swingably carried by the casing, and a trigger mounted between the signal and the casing, said trigger holding the signal in a safety-indicating position and having a portion confronting the free end of said element.

2. In a hygrometer, a moisture sensitive element consisting of a tubular membrane, a casing in which said element is contained, one end of the element being relatively stationary the other end of the element being free to move, a spring-loaded signal having a spindle turnably and slidably carried by the casing and having a portion confronting the free end of said element, and a trigger mounted on the spindle, having an end engageable with a portion of the casing upon sliding and turning the spindle against the spring loading to establish the signal in a safety-indicating position.

3. In a hygrometer, a moisture sensitive element consisting of a tubular membrane having an active end and an inactive end and being plugged at its active end, a casing in which said element is contained, the inactive end being relatively stationary the active end being free to move, a spring-loaded signal having a spindle, one end of the spindle having a pad confronting the plugged end, the other end of the spindle having a trigger with an angled end directed toward the signal, and a cap having a cover in which the spindle is turnably and slidably carried, being cut away to provide a window through which the signal is visible and an edge at which the angled end is engageable upon sliding and turning the spindle against the spring loading to establish the signal in a safety-indicating position, said cap being screwed onto the casing for adjustment to vary the initial setting of the pad in respect to the plugged end.

4. A moisture sensitive expansible and contractible element for a hygrometer or the like comprising a thin walled open ended tube formed of a single ply of seasoned wood shaving and

having uniformly parallel grain fibers encircling the tube.

5. A moisture sensitive expansible and contractible element for a hygrometer or the like comprising a thin walled open ended tube formed of a single ply of seasoned wood shaving and having uniformly parallel grain fibers continuously encircling the tube and having adhesively joined lapping end portions longitudinally reinforcing the tube.

6. In a hygrometer, a moisture sensitive element consisting of a tubular membrane, a casing in which said element is contained, mounting means in the casing for one end of the element the other end of the element being plugged and free to move, a spring-loaded signal swingably carried by the casing, and a trigger-pivoted on the casing, said trigger having a pad confronting the plugged end of the element and having an angled end holding the signal in a safety-indicating position.

7. In a hygrometer, a moisture sensitive element consisting of a tubular membrane, a casing in which said element is contained, said element

having an active end which is plugged and free to move, a spring-loaded signal swingably carried by the casing, a trigger pivoted on the casing, said trigger having a pad confronting the active end of the element and having an angled end holding the signal in a safety-indicating position, and a means against which the other and also plugged end of the element is mounted, said means being adjustable to shift the element thus to vary the initial setting of the trigger pad in respect to the plug in the active end of said element.

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