# A Fast Responding Electric Hygrometer [1]

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The performance characteristics of a fast responding electric hygrometer of high sensitivity are presented in some detail. The hygrometer is made by evaporating, under vacuum, potassium metaphosphate to obtain a thin film of material (3 microinches thick) on a specially treated glass blank. The logarithm of the resistance is approximately linear with relative humidity at constant temperature. The resistances vary from $4 \times 10^4$ to $10^{13}$ ohms. For the temperature range of $-40°$ to $+40°$ C, a group of nearly parallel calibration curves is obtained. The manufacturing process is sufficiently well controlled so that hygrometer elements, made in different batches, closely conform to a mean calibration curve. The average hysteresis for the hygrometer element over the temperature range $0°$ to $40°$ C is 2.7 percent relative humidity. The polarization effect for reversed direct current loading (1 minute cycles) is of the order of 0.3 percent relative humidity at the end of two hours; it is 1.4 to 2.2 percent for intermittent direct current loading (15 seconds on, 45 seconds off); and it is 3.7 to 6.8 percent for continuous direct current loading. Elements aged by humidity cycling appear to be less subject to polarization. Following a discrete change in relative humidity, the average response time of the element for a 63 percent change in indication at $-20°$ C, with an air velocity of 800 feet per minute parallel to the long edge of the element, is 1.9 seconds for a relative humidity change from 41.1 to 82.3 percent (with respect to water); it is 3.4 seconds for the same relative humidity change in the reverse direction. Times for 90 percent change in indication are 5.0 and 16.4 seconds, respectively. At room temperature, the average response time, for a 63 percent change in indication, with a velocity of 768 feet per minute, is 0.10 second for a discrete change in relative humidity from 33 to 80 percent, and 0.42 second for the same change in the reverse direction. Corresponding times for 90 percent change are 0.74 and 11.2 seconds. In comparison with lithium chloride elements currently produced for radiosonde use, the response time of the element was found to be less by at least an order of magnitude.

## 1. Introduction

At the present time, the device employed for sensing the moisture content of the upper air in soundings with the radiosonde is a modification of the electric hygrometer developed by Dunmore [1, 2, 3].[2] One form of this hygrometer comprises a flat strip of polystyrene base material, 4 in. long and $1\frac{1}{16}$ in. wide, with sputtered tin electrodes on the two long edges, that has been coated with an electrolytic film of aqueous lithium chloride dissolved in polyvinyl acetate, polyvinyl chloride, or polyvinyl alcohol. Another form comprises a flat strip of polystyrene base material 2 in. wide but otherwise essentially similar to the narrow type. The concentration of the lithium chloride solution, which is held on the base material by the plastic binder, varies with relative humidity. Since the resistance between the electrodes varies with concentration, it is then a measure of the ambient relative humidity.

One of the basic limitations of the lithium chloride hygrometer is its high time lag at low temperatures [4, 7]. Because of this, development work has focused on producing a faster responding hygrometer [5, 9]. The most successful, to date, is the carbon element [5] which, in flat strip form, appears to have a speed of response that is about four times as fast as the lithium chloride hygrometer. However, even with this increased speed of response,

the carbon element falls far short of adequately responding, at the high rates (1,000 fpm) of radiosonde balloon ascents now used and the still higher rates (2,000 fpm) anticipated, to humidity gradients that may exist in the upper air.

In considering the ways in which the upper air humidity might be measured by radiosonde means, it was apparent that the electric hygrometer has several very desirable features. It is inexpensive, small and light in weight, easy to use, and gives a response directly in terms of resistance. The search for a fast responding hygrometer was directed along lines that would retain as many of these features as possible. The most promising approach seemed to be to find a material whose surface resistivity was reversibly responsive to relative humidity.

All solids exhibit some degree of electrical conductivity both surface-wise and volume-wise, which increases with increasing relative humidity. In the early experiments, considerable attention was directed toward finding a material with a high volume to surface resistivity. It was felt that in order to obtain a fast responding element, it would be necessary to employ the adsorptive properties of a material, rather than its absorptive properties. In adsorption, the attainment of equilibrium between the adsorbed water vapor on the surface and the ambient relative humidity would be a relatively fast process, whereas in absorption, the attainment of equilibrium would be slow, since the water vapor would have to diffuse into the material. This immediately ruled out highly porous materials. This also explained and clarified the lag limitations

of the current lithium chloride element. This element uses a porous plastic binder to retain the lithium chloride solution on the surface of the base material. For equilibrium to be achieved, water vapor must diffuse into this binder until the lithium chloride solution has reached its equilibrium concentration. To improve the speed of response of the lithium chloride element, it would be necessary to decrease appreciably the film thickness. This has been attempted with some reduction in lag [9].

Initially, hygrometer elements were devised from such materials as glass, porcelain, other dielectrics, and plastics, all relatively high resistance sensors. The use of bifilar windings of B & S No. 40 platinum wire on tubular forms, intermeshing comb shaped electrode configurations on flat strips, and similar schemes, brought these high resistances down to some measurable and usable range. Even so, the resistance range of such an element encompassed at least six decades. This resulted in a remarkably high sensitivity. Furthermore, it appeared that for many materials, the logarithm of the resistance was roughly linear with relative humidity.

However, it was not until vacuum evaporated thin films were tried that elements of sufficient speed of response were obtained. Of the various films so far investigated, those formed by the vacuum deposition of potassium metaphosphate offer the most promise. The main purpose of this paper, therefore, is to present data in broad outlines on the design and performance of this type of hygrometer.

## 2. Elementary Theory

If a salt is dissolved in water, the equilibrium vapor pressure of the water will be depressed to some value lower than the saturation pressure of pure water. As the concentration of the salt in the solution is increased, this vapor pressure lowering continues until a minimum vapor pressure is reached for the solution at saturation. Further addition of salt normally has no effect on the vapor pressure. If the saturated salt solution is in a closed space, this ambient space will eventually assume a constant vapor pressure which is dependent on the particular salt as well as on the temperature. If the saturated salt solution is surrounded by an open space, there will be a net flow of water vapor in or out of the solution, depending on whether the ambient vapor pressure (or relative humidity) is greater or smaller than that of the saturated salt solution. If the flow is outward, the water will eventually evaporate completely leaving only dry salt. If the flow is inward, the solution will dilute until the concentration has decreased enough so that the equilibrium vapor pressure of the salt solution is the same as that of the ambient space.

Consider now a thin film of salt deposited on an insulator and exposed to air of constant relative humidity. If the ambient relative humidity exceeds the equilibrium relative humidity of a saturated solution of this salt, then the salt will sorb water and go into solution. This process will continue until the concentration of the salt solution produces an equilibrium relative humidity equal to the ambient relative humidity. By this time the thin film may have dissolved completely and the resultant solution may have washed off the surface of the base material. If the ambient relative humidity is at the equilibrium relative humidity of the saturated salt solution, then the salt will only sorb enough water to form a saturated solution. On the other hand, if the ambient relative humidity is below the equilibrium value of the saturated salt solution, the salt film will adsorb water vapor, but this adsorbed water vapor will remain in the vapor phase and will be held on the surface by physical bonding forces. The quantity of adsorbed water vapor will be a function of the ambient relative humidity. If the insulator on which the salt film is deposited has electrodes, it is possible to measure its resistivity and to relate this measurement with relative humidity.

A hygrometer of this type has an upper limit equal to the equilibrium relative humidity of the saturated solution of the salt. Thus, it is important that the salt chosen have an equilibrium relative humidity that is as close to 100 percent as possible.

Assuming that the mechanism is purely one of adsorption, the response of the film to humidity changes should be practically instantaneous. If, in addition to adsorption, there is some absorption, then superimposed on the initial fast response of the film will be a secondary slow response. The magnitude of this secondary effect, since it depends on diffusion, will depend on such parameters as film thickness, porosity, and temperature. Usually it is difficult, if not impossible, to completely eliminate absorption, but it may be possible to reduce it to a tolerable or even insignificant amount.

Another feature of the absorption phenomenon which is detrimental to satisfactory hygrometric use is the decided tendency toward nonreversibility. This may show up as a shift in indication with time or previous history, or a change in calibration slope.

## 3. Description of Hygrometer

The hygrometer consists of an insulating material containing two independent parallel electrodes and having a thin film of salt, deposited, under vacuum, on one surface. The size and shape of the base, the length and separation of the electrodes, and the thickness of the deposit can be varied to meet specific requirements. The base of the hygrometer used in this study of the performance characteristics is cut from 3 x 1 x $\frac{1}{32}$ in. glass microscope slides [3] to a final size of 3 x $\frac{1}{2}$ x $\frac{1}{32}$ in. The glass is treated by washing with detergent and water, rinsing with distilled water, immersing first in benzol and then in acetone, leaching in nitric acid at 80° C. for one hour and rinsing again with distilled water. The intent is to cleanse the surface thoroughly and remove any free alkali which might possibly contaminate the salt film. Silver paint [4] is sprayed along the long edges on one side of the blank producing two parallel

electrodes ⅛ in. wide, 3 in. long, and having a ¼ in. separation. The blanks are placed in a furnace and heated to, and maintained at, 507° C for 1½ hr. This serves both to fire the silver electrodes and anneal the glass. After cooling the furnace to 300° C in 20 min, the blanks are removed and allowed to return to room temperature. The electrodes are burnished with steel wool and the blanks again cleansed with detergent, distilled water, benzol, and acetone.

About 40 treated blanks are placed in the bell jar of a vacuum coating apparatus on an aluminum frame. A charge of 100 mg of potassium metaphosphate, made by the thermal decomposition of reagent grade potassium dihydrogen phosphate in air, is placed in a molybdenum crucible and positioned so that the blanks are 16¾ in. from the charge, the electrode side of the blanks facing the charge. The bell jar is evacuated to a pressure of $5 \times 10^{-5}$ mm Hg, 120 amp of current passed through the crucible and the charge completely evaporated.

Immediately upon removal from the bell jar each element is inserted in a test tube containing a desiccant. The test tube is sealed and stored at room temperature until opened for removal of the element prior to test or use.

## 4. Thickness of Film

The thickness of the evaporated film was measured by optical interferometer techniques using the 5876 A line of a helium discharge tube. An optical flat, half covered with aluminum foil, was placed on the aluminum frame in the bell jar along with the glass blanks and coated during a routine evaporation run. The evaporated film was then covered with a second flat and the displacement of the fringes at the sharp edge of the film was estimated. This displacement so measured corresponded to ¼ fringe, which is equal to about 3 microinches, thus giving this value for the thickness of the evaporated film.

## 5. Calibration

Several objectives were kept in mind in calibrating the elements. First was the necessity of establishing an average or normal calibration curve, resistance against relative humidity, for a number of temperatures. This normal is the average resistance, with certain safeguards, of a number of elements manufactured at different times, at a given humidity at each temperature of interest. Different hygrometer elements were tested at each temperature.

Secondly, it is necessary to know and set practical limits to the deviations, from the normal curves, of elements made from time to time presumably by following exactly the same procedure. The deviations can be determined by entering the normal curve with the resistance at various relative humidities of elements manufactured at different times and comparing the relative humidity obtained from the normal curve with the test humidities. The procedure of operating radiosondes to obtain data on

the relative humidity in the upper air is necessarily such that the calibration of the humidity elements must be as uniform as possible.

The hygrometer element was calibrated at 40°, 20°, 0°, −20°, and −40° C in terms of resistance versus relative humidity. Seventy-eight individual elements were calibrated; at 40°, −20°, and −40° C the elements were calibrated in groups of 16, while at 20° and 0° C, in groups of 15. At each test temperature, the group of elements comprised four randomly selected elements from each of four batches manufactured on January 11 and 12, 1954, except that at 20° C and 0° C one manufacturing batch was represented by three elements.

The elements were subjected to atmospheres of known relative humidity in the NBS pressure humidity apparatus [10]. Relative humidities for temperatures below 0° C are always for supercooled water, to conform to current meteorological practice. The relative humidity was known to an accuracy of at least 0.5 percent *RH*. The element resistance was measured with a d-c electrometer circuit with an accuracy of 10 percent of the measured value. This is equivalent to an accuracy of about ¾ of 1 percent *RH*.

The procedure employed was to expose the elements to successively increasing values of relative humidity, and then to successively decreasing values. At each relative humidity, the elements were permitted to "soak" until two or more arbitrarily chosen elements indicated little or no change in resistance in a 5-min interval of time. The resistance of an element was taken as the indicated value after current was permitted to flow through an element for 15 sec.

At the low temperatures, especially at −40° C, it was not feasible to obtain a complete calibration loop. Successively decreasing values of realtive humidities, therefore, were utilized principally.

From the data so obtained, average values of resistance were computed. For any test temperature, wherever possible, the mean of the resistances for increasing and decreasing relative humidity was calculated and used in plotting the curve of the logarithm of the resistance versus relative humidity. The calibration is shown as a group of dashed curves in figure 1.

Entry was made on the average calibration curves of figure 1 with the resistance value for each element at each test point and the indicated relative humidity so obtained was compared with the test humidity produced by the NBS pressure humidity apparatus to yield deviations.

A statistical study of the deviations was made in order to determine such factors as accuracy, repeatability, and manufacturing uniformity. The standard deviation for the entire calibration from +40° C to −40° C is 2.9 percent *RH*. The standard deviation at 40° C is 3.6 percent *RH*, at 20° C is 2.6 percent *RH*, at 0° C is 2.3 percent *RH*, at −20° C is 2.7 percent *RH*, and at −40° C is 3.8 percent *RH*. On the average, the standard deviation for any one element is 3.0 percent *RH*. If a deviation greater than 5 percent *RH* is considered unacceptable, in
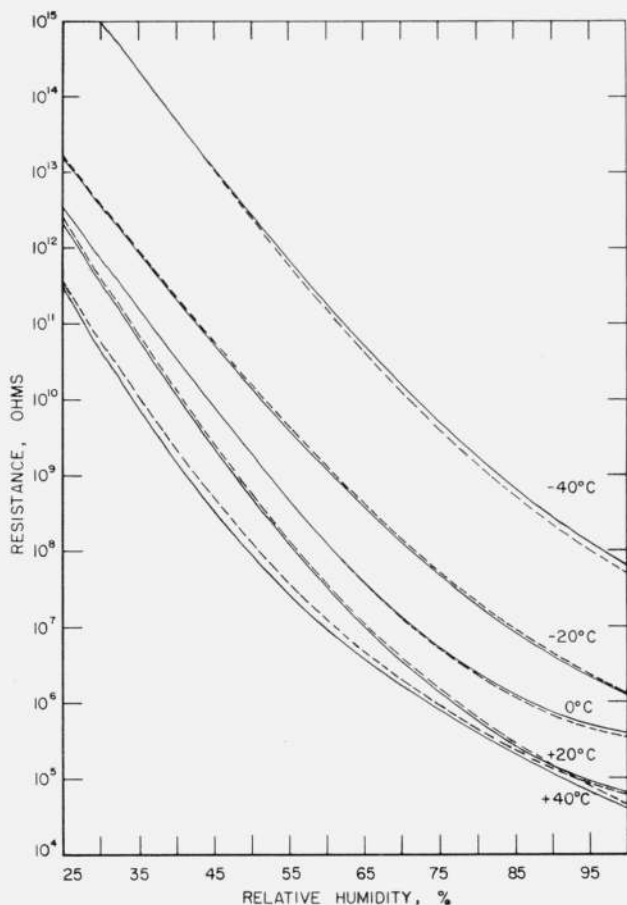
FIGURE 1. *Calibration of the fast responding hygrometer.*

The dashed lines represent the calibration based on the averages of all elements tested. The solid lines represent the adjusted calibration and are obtained by excluding all elements, from the averaging process, that have deviations greater than 5 percent relative humidity from the dashed calibration curves.

conformance with the basic calibration requirement of the standard radiosonde element [8], then 5 percent *RH* will encompass 1.7 standard deviations.

It may be deduced, therefore, that about 90 percent of all calibration points will have deviations from the mean calibration curves that are not greater than 5 percent *RH*.

If elements with one or more deviations greater than 5 percent *RH* are excluded from the averaging process in computing mean values, a group of adjusted calibration curves can be derived which is probably more significant for practical radiosonde use. The adjusted curves are shown in figure 1 as solid lines.

The number of elements with one or more deviations greater than 5 percent *RH* is 25. This corresponds to 33 percent of the elements. Similarly, the number of elements with one or more deviations greater than 7 percent *RH* is 10, corresponding to 13 percent of the elements. Only one element, 1 percent of the elements, had deviations greater than 10 percent *RH*. There does not appear to be any dependence or relation between fabrication batch

and magnitude of the deviations. Apparently, if the manufacturing conditions are closely duplicated, as was done in the four manufacturing batches from which elements were randomly selected for calibration, the mean calibration curves should suffice without individual calibration of each element. Furthermore, if each element is given a 1- or 2-point check at room temperature, and all elements with deviations greater than 5 percent *RH* discarded, the adjusted mean calibration curves should give the relative humidity with adequate accuracy for routine upper air meteorological sensing.

The adjusted mean calibration curves form a group of nearly parallel lines that are approximately linear between the logarithm of the resistance and the relative humidity from 25 to 75 percent *RH*. Greater departure from linearity in a direction to reduce sensitivity occurs above 75 percent *RH*. The useful resistance range extends from about $10^5$ to $10^{13}$ ohms, the upper limit being set by such factors as electrical leakage and pickup limitations in the measuring circuit. While the adjusted mean calibration curves (based on characteristics of selected elements) are more significant in use than the curves based on all elements tested, there is little difference between the two groups of curves except at high relative humidities.

## 6. Reliability of Standard Calibration Curve

Subsequent to the completion of the calibrations described above, two additional calibrations were made to determine whether elements fabricated on widely differing dates conform to a standard calibration. One group of nine elements, selected from two batches manufactured on March 29, 1954, was calibrated on April 30, 1954, at −20° C. A second group of 16 elements, selected from three batches manufactured on August 4, 1954, was calibrated on October 21, 1954, at 20° C.

The average results are shown in figure 2. The solid lines represent the calibrations obtained on elements manufactured January 11 and 12, 1954, and discussed above (section 5). The circles represent the calibration at −20° C of the elements manufactured on April 30, and the crosses, the calibration at 20° C of the elements manufactured on August 4.

Entry was made on the adjusted mean calibration curves of figure 1 with the resistance values for each element at each test point, the indicated relative humidity so obtained compared with the test humidity, and the deviations computed. The standard deviation for the nine elements calibrated at −20° C is 1.9 percent *RH* while for the 16 elements calibrated at 20° C is 3.4 percent *RH*. These standard deviations compare favorably with the values of 2.7 and 2.6 percent *RH* obtained in the original calibrations at −20° and 20° C (section 5).

The manufacturing procedure employed in fabricating elements on January 11 and 12, March 29, and August 4, is apparently uniform and repeatable, for the latter elements were made 2½ and 9 months later than those on which the adjusted average
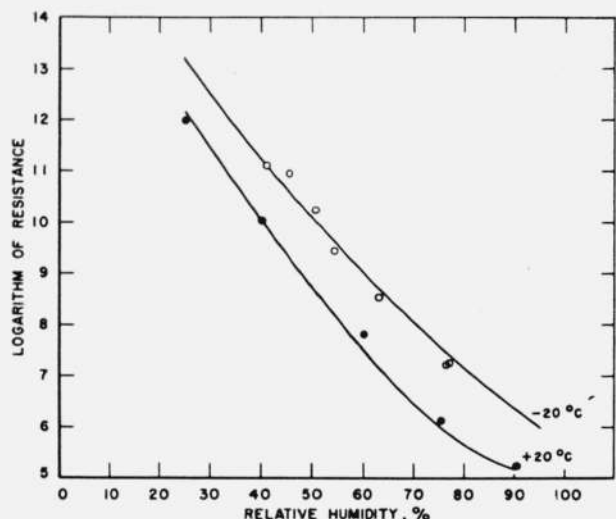
FIGURE 2. *Manufacturing reproducibility.*

Curves are based on elements manufactured on January 11 and 12, 1954 and are identical to the ones in figure 1 at +20° and −20° C. The circles represent −20° C calibration data obtained on elements manufactured April 30, 1954, while the crosses represent +20° C calibrated data obtained on elements manufactured on August 4, 1954.

calibration curve is based. It appears reasonable to assume that if elements are made in the manner previously described, they would conform to the adjusted mean calibration with sufficient accuracy for routine radiosonde use.

## 7. Hysteresis

In the process of obtaining the basic calibration data at 40°, 20°, and 0° C, the elements were first exposed to a low relative humidity, then to successively higher values of relative humidity, and finally to successively lower values thereby permitting the determination of hysteresis. At any ambient relative humidity, the difference in resistance of an element converted to equivalent percent relative humidity, for increasing and decreasing humidity, is defined as the hysteresis of that element at the ambient relative humidity. The average hysteresis is defined as the arithmetic average of the hysteresis for all the ambient test relative humidities for any given test conditions. The average hysteresis at 40°, 20°, and 0° C is given in table 1 at nominal ambient relative humidities of 25, 40, 60, and 75 percent. The average hysteresis is 2.2 per-

TABLE 1. *Hysteresis*

| Temperature °C | Relative humidity, % | | | | Mean |
|---|---|---|---|---|---|
| | 25 | 40 | 60 | 75 | |
| | Average hysteresis, % RH | | | | |
| 40 | 0.8 | 1.4 | 3.9 | 2.9 | 2.2 |
| 20 | 2.2 | 2.4 | 2.0 | 5.1 | 2.9 |
| 0 | 1.0 | 2.9 | 4.0 | 3.9 | 3.0 |
| 0 to 40 | ---- | ---- | ---- | ---- | 2.7 |

cent relative humidity at 40° C, 2.9 percent at 20° C and 3.0 percent at 0° C; the average hysteresis for the temperature range 0° to 40° C is 2.7 percent. There appears to be a tendency for the magnitude of the hysteresis to be greater at the higher ambient relative humidities. About 6 percent of the elements have a hysteresis greater than 7 percent RH, 39 percent have a hysteresis greater than 5 percent RH, and 83 percent have a hysteresis greater than 3 percent RH. The maximum hysteresis observed among all elements is 11.5 percent RH. In general, if an element is subjected to a humidity cycle of successively higher relative humidities and then successively lower relative humidities, the indicated relative humidities in the decreasing humidity direction are higher than in the increasing direction.

## 8. Polarization

The passage of direct current through an electric hygrometer element produces polarization. This phenomenon manifests itself as an increase in resistance and hence leads to an erroneous indication in relative humidity. It is important that an electric hygrometer that is used in a direct current circuit have little polarization so that errors from this source be small or negligible.

For radiosonde use, it is anticipated that the hygrometer elements will be employed with a d-c electrometer circuit. Elements were therefore tested under the current loading produced by such a circuit at room temperature and at a relative humidity of 75 percent. Each element was exposed in a sealed jar over a saturated solution of sodium chloride for ½ hr without current loading, and then tested for polarization with current flowing through the element. The test was made with current on for 15 sec and current off for 45 sec. The resistance of the element was approximately $10^6$ ohms and the current through the element was about $10^{-6}$ amp.

Two types of continuous current loading tests were also made: (a) the current was permitted to flow through the element continuously in one direction and (b) the current was permitted to flow through the element continuously, but the polarity was reversed at a frequency of 1 cpm.

Elements with two different histories were used in these tests. One group of elements was tested immediately upon removal of the elements from the test tubes in which they had been sealed after manufacture. The other group of elements was tested after the elements had been "humidity-cycled". This involved subjecting the elements to alternate high (about 80%) and low (about 33%) relative humidities at room temperature for 1 hr without current loading, the exposure at each humidity lasting 1 min. The polarization test on elements so treated was made 1 day subsequent to this treatment.

Four untreated elements and four "humidity-cycled" elements were tested in each manner. The results are shown in table 2.

Of the three methods of current loading investigated, the reversed current loading produces the least polarization. At the end of 2 hr, the average

TABLE 2. *Polarization at room temperature and 75 percent relative humidity*

| Type of current flow through element | Average decrease in indicated relative humidity, percent, after | | |
|---|---|---|---|
| | ½ hr | 1 hr | 2 hr |
| | Untreated elements | | |
| 15 sec on—45 sec off | 0.8 | 1.3 | 2.2 |
| Continuous | 4.4 | 5.7 | 6.8 |
| Reversed polarity—1 min cycles | | | 0.4 |
| | "Humidity-cycled" elements | | |
| 15 sec on—45 sec off | 0.8 | 1.1 | 1.4 |
| Continuous | 1.9 | 2.6 | 3.7 |
| Reversed polarity—1 min cycles | | | 0.2 |

observed decrease in indicated relative humidity for the untreated elements was 0.4 percent and for the "humidity-cycled" elements, 0.2 percent. These magnitudes are negligible as applied to routine radiosonde use. However, it must be noted that during the 1-min period that current flows through an element in one direction, the indicated relative humidity decreases about 2 percent. On reversal of the current, the element first recovers but then



FIGURE 3. *Typical recording of a reversed current polarization test for an untreated fast responding hygrometer element.*

repeats the previous pattern. The end point, that is, the indicated relative humidity at the end of the 1-min period, was used for determining polarization. Part of a typical recording of a reversed current polarization test is shown in figure 3.

The 15 sec on—45 sec off current loading produces somewhat more polarization. At the end of 2 hr, the average decrease in indicated relative humidity for the untreated elements was 2.2 percent and for the "humidity-cycled" elements, 1.4 percent. Again, the magnitude of the polarization for routine radiosonde use is small.

The polarization resulting from continuous current loading is much greater than that produced by the other loadings. At the end of 2 hr, the average decrease in indicated relative humidity for the un-untreated elements was 6.8 percent and for the "humidity-cycled" elements, 3.7 percent.

A comparison of the polarization in the untreated and "humidity-cycled" elements indicates that the polarization error is reduced, approximately, by a factor of two, if the elements are humidity-cycled.

## 9. Speed of Response

The speed of response of the hygrometer was measured at room temperature and at −20° C and compared against that of the narrow lithium chloride electric hygrometer currently used with the radiosonde. At room temperature, a simple humidity lag apparatus, in which the relative humidity could be switched from one value to another in a fraction of a second, was used. At −20° C, the NBS divided flow humidity apparatus [6] was used. With this device, the relative humidity could be switched, similarly, from one value to another in less than a second. The response of the hygrometer was recorded on either a Brown strip-chart recorder or a Brush recorder. From these data the times required for the hygrometer to undergo a change in indication of 63 and 90 percent were obtained.

At room temperature, the change in relative humidity used in this study was nominally 33 to 80 percent. At −20° C, the change was 50 to 100 percent, based on ice, which is equivalent to 41.1 to 82.3 percent, based on supercooled water. The air speed during the room temperature tests was 768 fpm while at −20° C it was 800 fpm. The direction of air flow was parallel to and in the direction of the long dimension of the hygrometer. Four fast responding elements and four lithium chloride elements were used in the room temperature tests, while at −20° C three fast responding elements and four lithium chloride elements were used. With each fast responding and lithium chloride element, the relative humidity was changed from a low to high and then high to low value two or more times. The average measured speeds of response are presented in table 3.

The table shows that for humidity increasing, the fast responding element has roughly a consistent 30 to 50-fold increase in response time under all conditions of test. For decreasing humidity the increase in response time is substantially less and
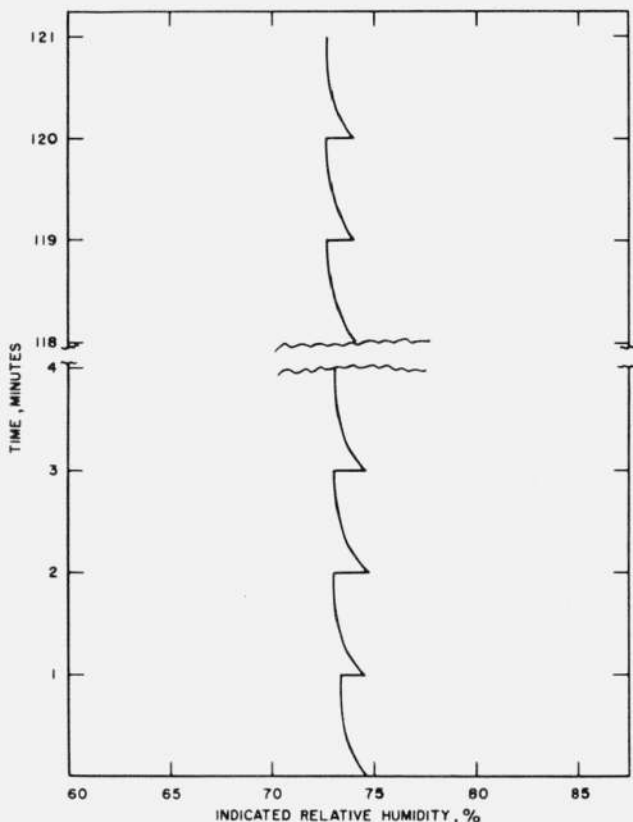
TABLE 3. *Speed of response*

The values of relative humidity at $-20°$ C are for supercooled water

| Element | Temperature | Increasing humidity change | | | Decreasing humidity change | | |
|---|---|---|---|---|---|---|---|
| | | $RH$ % | % Change in indication 63    90 | | $RH$ % | % Change in indication 63    90 | |
| | | Average speed of response, seconds | | | | | |
| Fast response | Room | 33 to 80 | 0.10 | 0.74 | 80 to 33 | 0.42 | 11.2 |
| LiCl | Room | 33 to 80 | 3.0 | 35.2 | 80 to 33 | 5.9 | 24.5 |
| Ratio | | | 30 | 48 | | 14 | 2 |
| Fast response | $-20°$ C | 41.1 to 82.3 | 1.9 | 5.0 | 82.3 to 41.1 | 3.4 | 16.4 |
| LiCl | $-20°$ C | 41.1 to 82.3 | 59 | 201 | 82.3 to 41.1 | 98 | 216 |
| Ratio | | | 31 | 40 | | 29 | 13 |
| Fast response: Ratio | $-20$/room | | 19 | 7 | | 8 | 1.5 |
| LiCl: Ratio | $-20$/room | | 20 | 6 | | 17 | 9 |

more variable, the increase ranging from 2 to 29-fold. However, the increase in response speed is greatest at the lower temperatures where improvement is the most needed in making upper air observations in view of the response times of the lithium-chloride element at $-20°$ C of over 3 min.

Inspection of table 3 shows that the response time is tremendously affected by the direction in which the humidity is changing and by temperature in general increasing rapidly as the temperature of the elements decreases. In general the fast-responding element responds more rapidly for increasing than decreasing relative humidity changes.

Typical response curves at room temperature and at $-20°$ C are shown in figures 4 and 5.

At room temperature, the fast responding element response curve exhibits a "kink" or reversal. In the increasing $RH$ direction this corresponds to about $1\frac{1}{2}$ percent $RH$; in the decreasing $RH$ direction the reversal is of the order of 10 percent $RH$. The reversal may be explained by postulating that a heat of adsorption is evolved on increasing the ambient relative humidity while on decreasing the ambient relative humidity, the desorption of water vapor from the film is accompanied by a loss of heat or cooling. The heating or cooling tends to be adiabatic. Thus, for decreasing $RH$, the cooling decreases the salt film temperature as well as that of a thin film of air surrounding the element. Since the absolute humidity remains fixed, the relative humidity of the air film increases. The element immediately responds to this higher $RH$ producing a reversal in the response curve. However, the main air stream quickly returns the element to temperature equilibrium, causing a second reversal in the response curve and permitting the element to approach its final value. The magnitude of the reversal is controlled by two factors. One is the rapid speed of response of the element which drives the resistance to its final value; the other is the adiabatic temperature change which acts on the element in the opposite direction, that is, it tends to drive the resistance of the element back toward its initial value. The interaction of these two phenomena may produce the kink and determine its size.

At $-20°$ C, no kink was observed. This is explainable if the adiabatic temperature change accompanying adsorption and desorption is too small
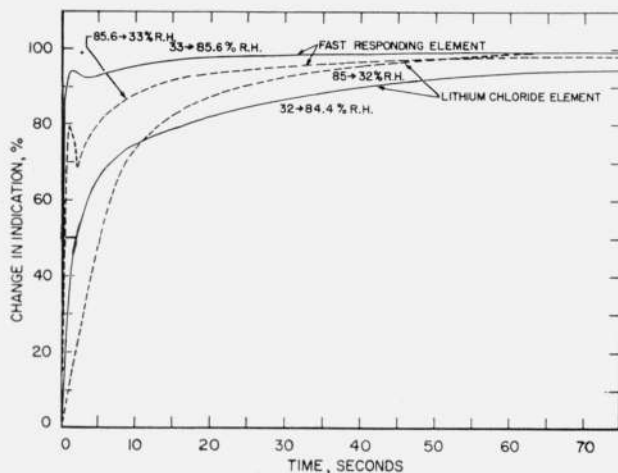


FIGURE 4. *Typical response curves at room temperature.*
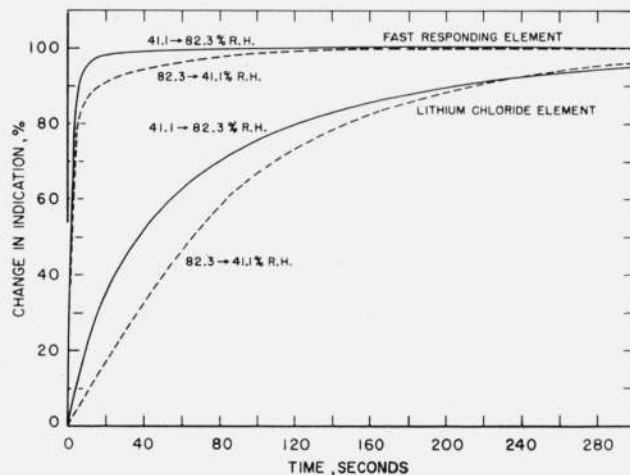


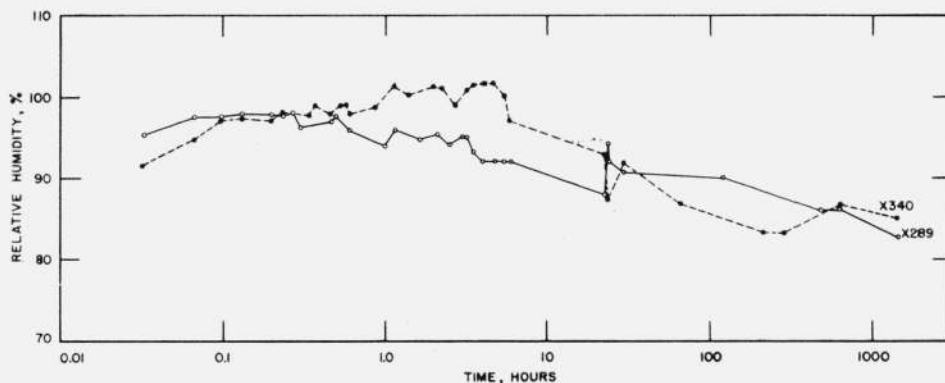FIGURE 5. *Typical response curves at $-20°$ C.*

FIGURE 6. *Exposure over water.*

Change in indicated relative humidity with time of two fast responding hygrometer elements.

to produce any detectable effect. The smallness of the temperature change, in turn, is explainable by the relatively small amounts of water vapor involved in the adsorption process and, hence, small amounts of heat.

No kink or reversal in the response curve has been observed with the lithium chloride element. The heat of solution, as the solution of lithium chloride on the element increases and decreases its concentration with decreasing and increasing relative humidity, should raise or lower the film temperature. Since the water vapor must diffuse through the plastic binder, the rate of heating or cooling of the film is relatively slow and hence the tendency for an adiabatic temperature change is greatly reduced since the thermodynamic process becomes principally isothermal. Consequently the response curve does not exhibit a kink or reversal.

## 10. Exposure to High Humidity

Two fast responding hygrometer elements were subjected to high humidity for an extended period of time to determine if such exposure would have a deleterious effect. Each element was suspended in still air over distilled water in a sealed glass jar, at room temperature. The resistance of each element was measured at frequent intervals of time, and entering the adjusted calibration curve (fig. 1) with this resistance, the indicated relative humidity was obtained. The results are plotted in the curves of figure 6.

For a period of 3 to 6 hr, the elements indicated the correct nominal relative humidity. Some fluctuations were observed, probably due to fluctuations in room temperature and radiation from or to the jar, which were reflected as fluctuations in relative humidity within the sealed jar. Continued exposure of the elements from 6 to 1,470 hr produced a pro-

gressive decrease in indicated relative humidity. At the termination of the test, one element indicated a relative humidity of 85 percent and the other, 83 percent.

After approximately 10 hr of exposure, several droplets of moisture were observed on the surfaces of the elements. While the size and number of these droplets did not appear to change, a large drop of liquid accumulated at the bottom of each element. From time to time, some of the liquid presumably flowed off the element into the water in the sealed test jar.

## 11. References

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