

Low-Temperature Performance of Radiosonde Electric Hygrometer Elements¹

By Arnold Wexler

The performance of radiosonde electric hygrometer elements was investigated in the temperature range from 0 to -40° C. It was found that an element indicated relative humidity with an average deviation of ± 2.4 -percent relative humidity from the average calibration for all of the elements tested. The maximum deviation in indication of any element did not exceed 10.5-percent relative humidity. The lag in response was found to increase markedly with decrease in temperature, to depend upon the magnitude and direction of relative humidity change, and the relative humidity from which the change was made.

I. Introduction

In the meteorological sounding of the upper atmosphere by means of the radiosonde, the device generally used in this country for humidity measurement is the electric hygrometer developed by Dunmore.² In a radiosonde flight in the temperate zone, temperatures below 0° C may be encountered from the ground up during the winter months, whereas during the summer months, freezing temperatures usually exist above 18,000 feet. Since a flight may reach an elevation of 80,000 feet, the greater proportion of the ascent will be at low temperatures. Information on the characteristics of the electric hygrometer at temperatures below 0° C is therefore important. Glückauf³ has reported both calibration and lag data on the coil type of electric hygrometer at low temperatures. Data at low temperatures on the flat-strip hygrometer element used in radiosondes are very meager. An investigation was therefore undertaken to determine the performance of the flat-strip electric hygrometer at low temperatures.

II. Description of Hygrometer

The hygrometer most readily available, and therefore used in this study, was one in current

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² F. W. Dunmore, J. Research NBS **20**, 723 (1938) RP1102; F. W. Dunmore, J. Research NBS **23**, 701 (1939) RP1265; H. Diamond, W. S. Hinman, F. W. Dunmore, and E. G. Lapham, J. Research NBS **25**, 327 (1940) RP1329.

³ E. Glückauf, Proc. Phys. Soc. (London) **50**, 344 (1947).

manufacture. This element, which is a modification of the original Dunmore design, and which is used by the Weather Bureau, Navy, and Army, is made by coating a flat strip of polystyrene base, 4 in. long and $\frac{1}{16}$ in. wide, with an electrolytic film of lithium chloride dissolved in polyvinyl acetate or polyvinyl chloride, and sputtering tin electrodes on the two long edges. The resistance between the electrodes varies with relative humidity. This resistance, operating in the relaxation oscillator circuit of the radiosonde transmitter, controls the value of the audiofrequency to which the carrier wave is modulated.

III. Experimental Procedure

An experimental procedure was adopted that would subject the element as far as practical to conditions simulating those encountered in a radiosonde flight. Standard equipment was employed. A radiosonde was utilized to transmit the response of the element to humidity changes; a radio receiver to detect the intelligence from the radiosonde transmitter; an electronic frequency meter and a recorder to automatically record the data in terms of audio frequency or recorder divisions. One recorder division was equal to 2 c/s.

The temperature circuit of the radiosonde was modified to provide an additional humidity circuit. A sequence switch that automatically changed the transmitted signal from one humidity circuit to the second humidity circuit to a reference

frequency and back to the first humidity circuit was connected to the radiosonde. The radiosonde was permitted to transmit a signal continuously, the duration of which was 23 sec on one humidity circuit, 22 sec on the other humidity circuit, and 15 sec on the reference frequency, a complete cycle lasting 60 sec.

Known humidities at constant temperature were obtained by utilizing the divided flow, low temperature humidity apparatus.⁴ This equipment produced an air atmosphere whose relative humidity, with respect to ice, was known to an accuracy of 3 percent.

The test procedure employed was to insert one or two elements into the test chamber of the humidity apparatus which had been brought to and maintained at a desired temperature. Each element was removed from its sealed vial immediately before test and inserted into the test chamber of the apparatus at as low a relative humidity as could be measured and recorded. The air velocity in the test chamber was adjusted to 525 ft/min. The element was tested with its length vertical and air flowing parallel to the length. The element was subjected in discrete steps of 16.7 percent to increasing values of relative humidity up to 100 percent, and back again to the lowest relative humidity. The change from one value of relative humidity to another took 1 to 2 sec. The element was exposed to a relative humidity long enough for the recorded reading to become constant. A total of 29 elements were used in this investigation.

IV. Data and Results

The hygrometer was subjected to a humidity calibration at nominal temperatures of -1° , -10° , -20° , -30° , and -40° C. Four or more units were tested at each temperature, and each unit supplied the data for one humidity cycle at one temperature. These data were in terms of relative humidity versus recorder divisions. By applying the standard frequency-resistance relationship for radiosondes, which was found to apply to the radiosonde used, the data were converted into relative humidity versus resistance for each humidity element. These are tabulated in table 1.

⁴ A. Wexler, J. Research NBS **40**, 479 (1948) RP1894.

The logarithms of the average resistance values from table 1 are plotted against the logarithms of the relative humidity in figure 1. In this graph only the values of resistance measured for increasing changes of relative humidity, that is, from low relative humidity to 100 percent, were used in order to eliminate hysteresis effects and reduce polarization and exposure effects as much as possible. A family of straight lines was obtained for values of relative humidity of 50 percent and above. Below 50 percent, there is a slight bow in the curves for -1.1° and -9.9° C, in the direction of higher resistance.

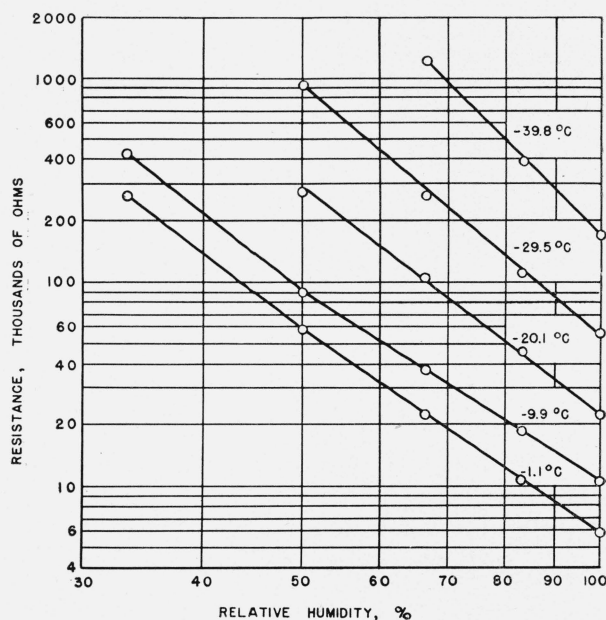


FIGURE 1. Logarithm of average resistance of the electric hygrometer versus logarithm of relative humidity at low temperatures.

By entering the curves of figure 1 with the resistances for each hygrometer element, as given in table 1, values of indicated relative humidity are obtained. The difference between this indicated relative humidity and the actual relative humidity may be considered a measure of the spread in indication to be expected from individual elements. The indicated relative humidity is the algebraic sum of the actual relative humidity and the difference. These differences are given in table 2 and show that the hygrometer at low temperatures will indicate the relative humidity with an average deviation of ± 2.4 -percent relative humidity from a mean calibration of all the

TABLE 1. *Low-temperature calibration—relative humidity versus resistance*

NBS No.	24	25	26	27	28	29	Average
Date of run	11-17-47	11-17-47	12-1-47	12-1-47	12-1-47	12-1-47	
Temperature, ° C	-1.2	-1.2	-1.0	-1.0	-1.2	-1.2	-1.1
Relative humidity, %	Resistance, ohms						
33.3	177,000	387,000	177,000	280,000	282,000	279,000	262,000
50.0	52,300	70,500	53,000	57,500	-----	-----	58,300
66.7	20,700	27,000	20,700	22,500	-----	-----	22,700
83.3	11,500	11,500	10,400	11,200	-----	-----	11,100
100.0	6,100	6,200	5,600	6,450	6,450	6,400	6,200
83.3	11,300	11,200	9,900	10,700	-----	-----	10,800
66.7	20,900	27,000	20,000	23,200	-----	-----	22,800
50.0	54,300	74,000	51,000	60,500	-----	-----	60,000
33.3	180,000	394,000	158,000	334,000	271,000	269,000	268,000
NBS No.	1	2	3	4	-----	-----	-----
Date of run	6-19-47	6-19-47	6-23-47	6-23-47	-----	-----	-----
Temperature, ° C	-9.4	-9.8	-13.2	-10.1	-----	-----	-9.9
33.3	272,000	455,000	520,000	455,000	-----	-----	425,000
50.0	65,000	99,000	102,000	94,000	-----	-----	90,200
66.7	31,200	38,000	44,000	39,900	-----	-----	38,300
83.3	17,700	18,200	21,500	19,900	-----	-----	19,300
100.0	9,800	10,300	11,900	10,800	-----	-----	10,500
83.3	14,800	17,000	20,100	18,700	-----	-----	17,600
66.7	28,000	38,800	42,500	39,000	-----	-----	37,300
50.0	61,000	103,000	101,000	93,000	-----	-----	89,500
33.3	250,000	500,000	520,000	430,000	-----	-----	425,000
NBS No.	5	6	9	10	-----	-----	-----
Date of run	6-27-47	6-27-47	10-20-47	10-20-47	-----	-----	-----
Temperature, ° C	-19.7	-20.1	-20.4	-20.1	-----	-----	-20.1
50.0	210,000	192,000	226,000	500,000	-----	-----	282,000
66.7	94,000	91,000	93,000	149,000	-----	-----	107,000
83.3	42,000	42,500	43,000	57,000	-----	-----	46,100
100.0	21,200	23,200	22,900	26,200	-----	-----	23,400
83.3	40,000	41,500	56,000	53,500	-----	-----	47,700
66.7	93,000	88,500	156,000	139,000	-----	-----	119,000
50.0	255,000	175,000	510,000	465,000	-----	-----	351,000
NBS No.	7	11	16	17	-----	-----	-----
Date of run	6-1-47	10-23-47	10-30-47	10-30-47	-----	-----	-----
Temperature, ° C	-29.7	-29.4	-29.2	-29.7	-----	-----	-29.5
50.0	890,000	950,000	1,400,000	500,000	-----	-----	935,000
66.7	275,000	310,000	293,000	197,000	-----	-----	269,000
83.3	103,000	125,000	111,000	106,000	-----	-----	111,000
100.0	51,000	60,000	54,500	52,500	-----	-----	54,000
83.3	107,000	117,000	162,000	117,000	-----	-----	126,000
66.7	279,000	271,000	570,000	260,000	-----	-----	345,000
50.0	770,000	830,000	2,000,000	710,000	-----	-----	1,080,000
NBS No.	8	12	13	14	15	-----	-----
Date of run	10-7-47	10-28-47	10-28-47	10-28-47	10-28-47	-----	-----
Temperature, ° C	-40.2	-39.6	-39.6	-39.7	-39.7	-----	-39.8
66.7	1,130,000	930,000	880,000	1,100,000	930,000	-----	994,000
83.3	400,000	395,000	395,000	-----	-----	-----	397,000
100.0	182,000	170,000	159,000	162,000	192,000	-----	173,000
83.3	390,000	342,000	342,000	-----	-----	-----	358,000
66.7	1,130,000	780,000	725,000	700,000	770,000	-----	821,000

TABLE 2. *Difference between indicated and actual relative humidity at low temperature*

The indicated relative humidity is the algebraic sum of the actual relative humidity and the difference

NBS No. Date of run Temperature, ° C	24 11-17-47 -1.2	25 11-17-47 -1.2	26 12-1-47 -1.0	27 12-1-47 -1.0	28 12-1-47 -1.2	29 12-1-47 -1.2	Average
Actual relative humidity, %	Relative humidity difference, %						
33.3	+3.7	-3.7	+3.7	-0.7	-0.8	-0.7	±2.2
50.0	+1.7	-2.3	+1.5	+2	-----	-----	±1.4
66.7	+2.0	-3.5	+2.0	+3	-----	-----	±2.0
83.3	-1.0	-1.0	+1.5	-3	-----	-----	±1.0
100.0	0.0	0.0	+3.0	-2.0	-2.0	-1.7	±1.4
83.3	-8	-3	+2.7	+0.9	-----	-----	±1.2
66.7	+1.8	-3.5	+3.2	-5	-----	-----	±2.2
50.0	+1.0	-3.0	+2.1	-2	-----	-----	±1.6
33.3	+3.6	-4.6	+4.9	-2.3	-0.5	-0.4	±2.7
NBS No. Date of run Temperature, ° C	1 6-19-47 -9.4	2 6-19-47 -9.8	3 6-23-47 -10.2	4 6-23-47 -10.1	-----	-----	-----
33.3	+4.0	-0.8	-1.9	-0.7	-----	-----	±1.8
50.0	+5.7	-1.2	-1.4	-8	-----	-----	±2.3
66.7	+3.8	-0.5	-1.5	-1.4	-----	-----	±1.8
83.3	+1.7	+7	-3.5	-1.5	-----	-----	±1.8
100.0	+2.5	+1.0	-1.7	-0.5	-----	-----	±1.4
83.3	+6.5	+2.6	-1.8	+2	-----	-----	±2.8
66.7	+6.6	-0.9	-2.7	-9	-----	-----	±2.8
50.0	+6.9	-1.7	-1.3	-5	-----	-----	±2.8
33.3	+4.9	-1.5	-1.9	-3	-----	-----	±2.2
NBS No. Date of run Temperature, ° C	5 6-27-47 -19.7	6 6-27-47 -20.1	9 10-20-47 -20.4	10 10-20-47 -20.1	-----	-----	-----
50.0	+4.2	+5.9	+3.2	-7.4	-----	-----	±5.2
66.7	+1.1	+1.8	+1.5	-6.7	-----	-----	±2.8
83.3	+1.6	+1.5	+0.7	-5.1	-----	-----	±2.2
100.0	+3.0	+0.2	+7	-3.0	-----	-----	±1.7
83.3	+2.8	+2.2	-4.6	-3.5	-----	-----	±3.3
66.7	+1.3	+2.3	-7.7	-5.7	-----	-----	±4.2
50.0	+1.5	+7.5	-7.8	-3.5	-----	-----	±5.1
NBS No. Date of run Temperature, ° C	7 6-1-47 -29.7	11 10-23-47 -29.4	16 10-30-47 -29.2	17 10-30-47 -29.7	-----	-----	-----
50.0	+0.4	-0.5	-4.8	+8.0	-----	-----	±3.4
66.7	+6	-1.5	-0.5	+6.3	-----	-----	±2.2
83.3	+1.9	-2.0	+2	+1.4	-----	-----	±1.4
100.0	+1.0	-3.0	-7	0.0	-----	-----	±1.2
83.3	+0.9	-0.8	-7.0	-6	-----	-----	±2.3
66.7	+5	+1.0	-10.5	+1.3	-----	-----	±3.3
50.0	+2.3	+1.3	-8.6	+3.3	-----	-----	±3.9
NBS No. Date of run Temperature, ° C	8 10-7-47 -40.2	12 10-28-47 -39.6	13 10-28-47 -39.6 ;	14 10-28-47 -39.7	15 10-28-47 -39.7	-----	-----
66.7	-2.0	+1.3	+2.0	-1.4	+1.3	-----	±1.6
83.3	-1.3	-0.8	-0.8	-----	-----	-----	±1.0
100.0	-1.0	+5	+2.0	+2.0	-2.2	-----	±1.5
83.3	-0.3	+2.1	+2.2	-----	-----	-----	±1.5
66.7	-2.0	+4.1	+5.3	+5.6	-4.1	-----	±4.2
-----	-----	-----	-----	-----	-----	-----	Mean ±2.4

elements tested. There is a tendency for these differences to be larger at the lower humidities and smaller at the higher humidities. The maximum difference did not exceed 10.5-percent relative humidity.

The dependence of the calibration upon temperature is given in tables 1 and 2 and figure 1. The curves in figure 1 essentially show that the primary effect of temperature is to produce a parallel displacement of the calibration, a higher humidity being indicated as the temperature is lowered. There also appears to be a small change in slope of calibration curve, but this is a secondary effect.

By interpolating values of resistance for relative humidities of 50, 60, 80, and 100 percent from figure 1, converting these into recorder divisions, and plotting them with curves redrawn from the manufacturer's calibration chart for the humidity element, a comparison between the calibration contained in this investigation and the manufacturer's calibration was obtained. This is shown in figure 2. From -1° to -40° C, the two calibrations agree within 5 to 7 percent.

In going through a cycle of increasing and then decreasing humidity, the elements, in general, exhibited hysteresis; the indicated relative humidities during the decreasing half of the cycle were sometimes greater and sometimes less than those measured during the increasing half of the cycle. See table 2 for the data. The magnitude of the differences between increasing and decreasing readings in some elements was 1-percent relative humidity or less; in other units it was observed to be considerably greater. One element (NBS No. 9) changed its indicated relative humidity reading by 11-percent relative humidity in going from an actual relative humidity of 50 to 100 percent and back to 50 percent. Several elements (NBS Nos. 10, 13, 14, 16, and 17) changed their readings by as much as 3- to 7-percent relative humidity.

The lag in response to changes in relative humidity was studied over the range of temperatures from -1 to -40° C. The procedure followed was to shift from one relative humidity to another as rapidly as possible (1 to 2 sec), transmitting and recording a humidity signal for 23 sec during 1-min cycles. From the data thus obtained, the lag constant (the time required for 62 percent of the humidity change to occur) was computed.

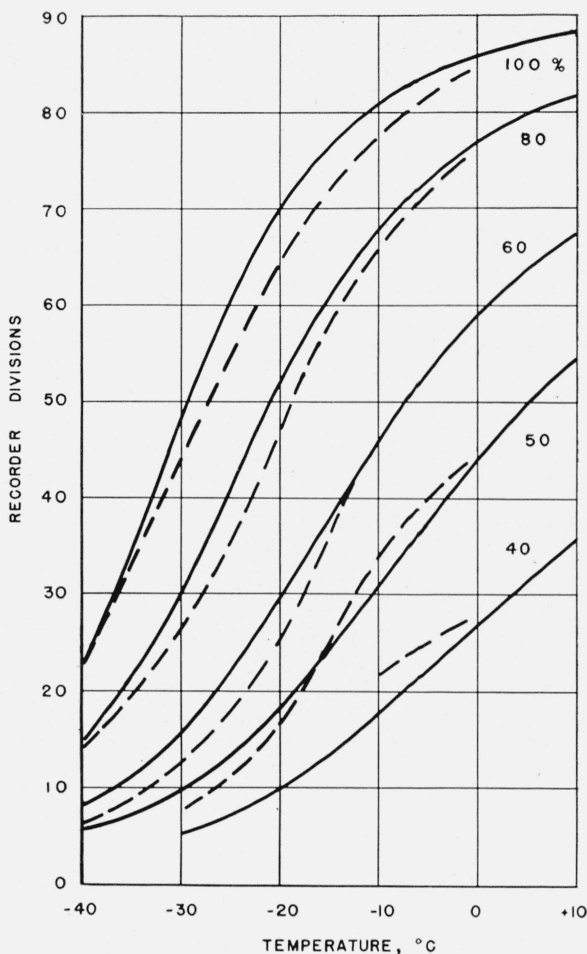


FIGURE 2. Comparison of NBS and manufacturer's calibration of the electric hygrometer at low temperatures.

Broken line is NBS calibration.

The time response of the hygrometer at low temperatures, although not a simple exponential function, still permitted the calculation of a lag constant with fair approximation. There was variation up to 30 percent in lag constant from element to element when subjected to the same relative humidity change at the same temperature. The lag was found to depend upon temperature, magnitude, and direction of the relative humidity change, and the relative humidity at which the change was made. Figure 3 shows the effect of these variables upon the lag constant. The lag constants used in figure 3 are the averages of two to eight values.

The lag constant was increased by (1) lowering the temperature, (2) increasing the magnitude of the humidity change, and (3) increasing the

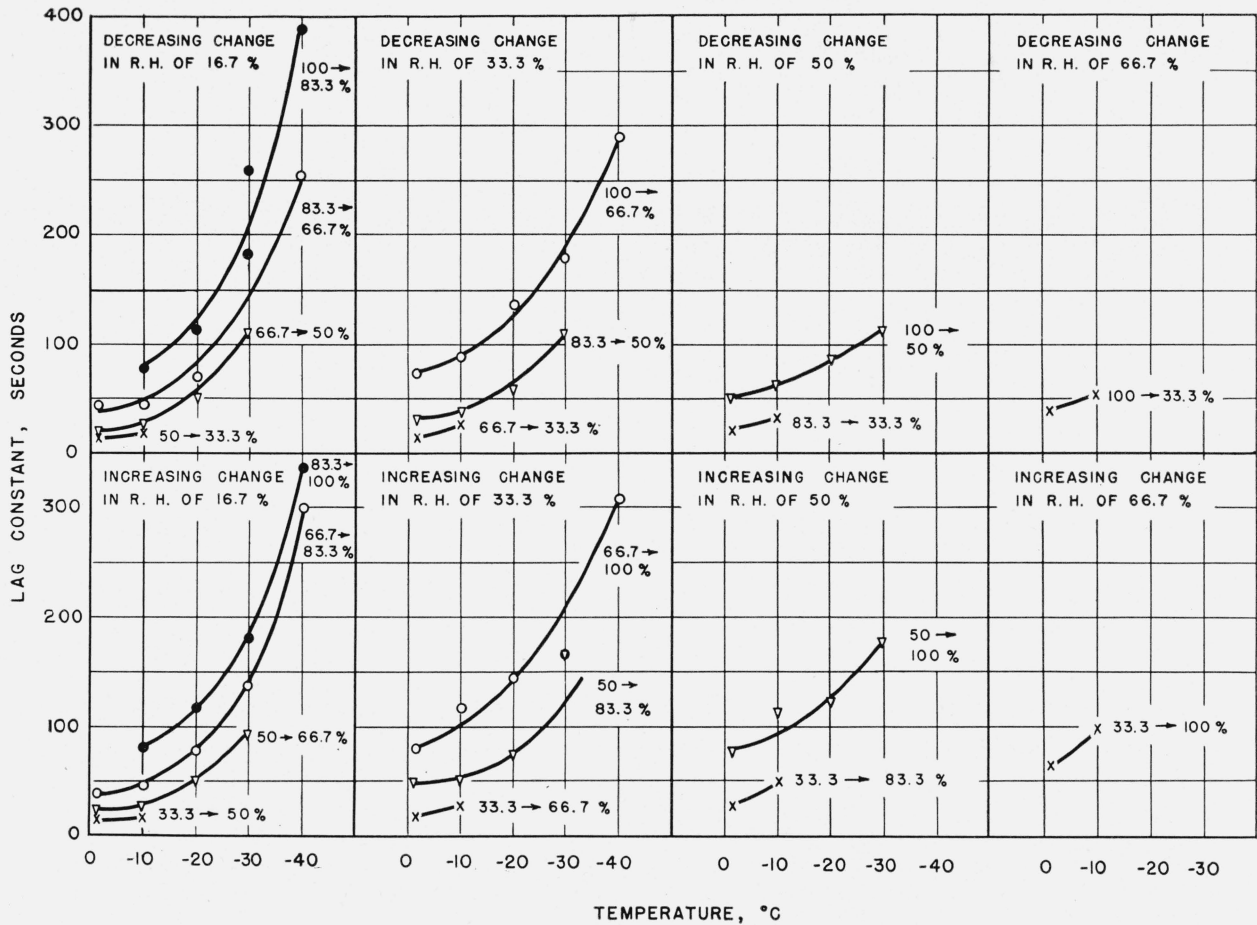


FIGURE 3. Factors affecting the lag constant.

The magnitude and direction of the change in relative humidity is shown on each curve.

initial value of the relative humidity from which the humidity change is made. For relative humidity changes of 16.7 and 33.3 percent, the lag constant was independent of direction, whereas for changes of 50 and 66.7 percent the lag constant in the increasing humidity direction was larger. The influence of these factors on the lag may also be demonstrated by time response curves for typical elements. In figure 4 is shown the time response of a single element at -20°C to a sudden change in relative humidity of 16.7 percent at various initial relative humidities. The effect of magnitude of humidity change on the time response is shown in figure 5 for a typical element at -20°C ,

in which discrete jumps of 16.7, 33.3, and 50 percent were made from an initial relative humidity of 50 percent. In figures 4 and 5, the humidity coordinate has been plotted on the basis of percentage change in relative humidity indication. Thus a total change of, say, 16.7-percent relative humidity is plotted on a scale of 100. An ordinate reading of 25 percent, therefore, represents 25 percent of the humidity change, that is, 25 percent of 16.7-percent or 4.2-percent relative humidity. The effect of temperature on the time responses is given in figure 6 for a relative humidity change of 66.7 to 83.3 percent. Each curve in this figure was obtained on a different unit.

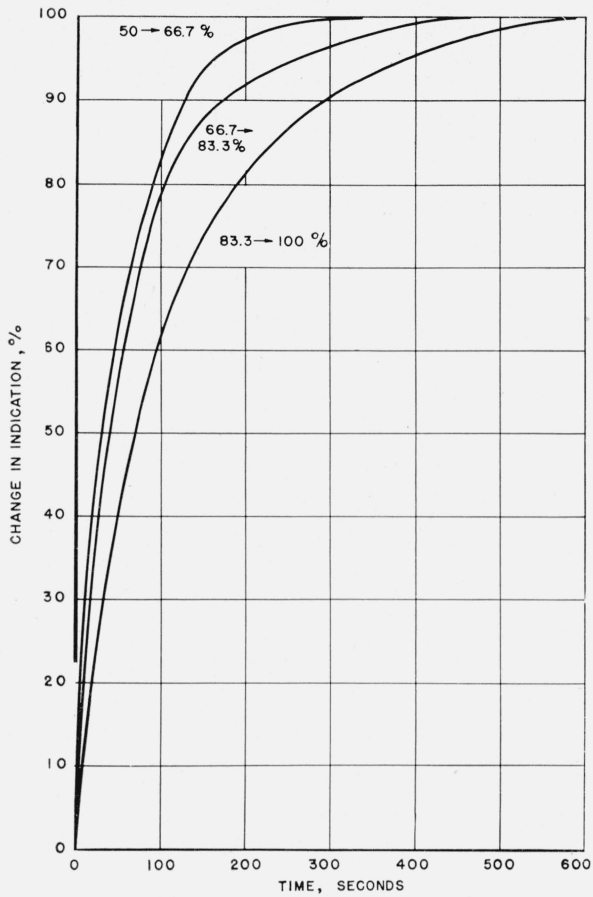


FIGURE 4. Time response of a typical element at -20°C for a sudden change in relative humidity of 16.7 percent from various initial relative humidities.

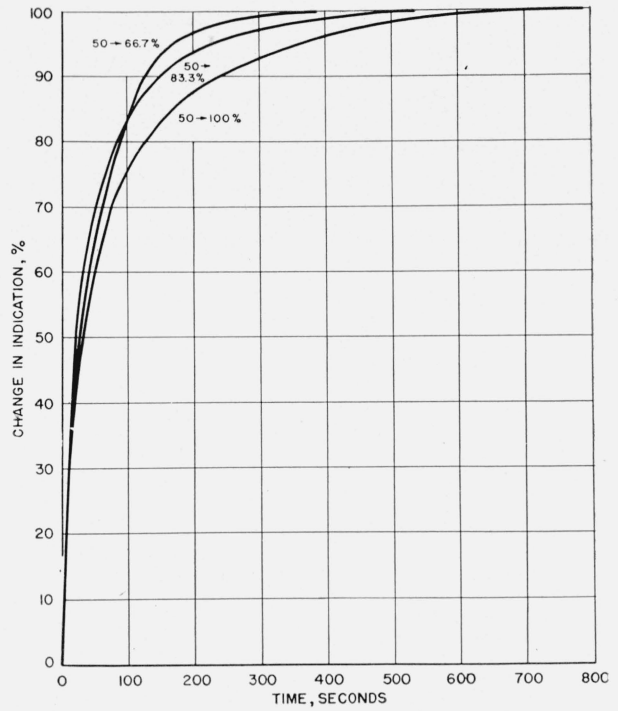


FIGURE 5. Time response of a typical element at -20°C for discrete changes in relative humidity of 16.7, 33.3, and 50 percent made from an initial relative humidity of 50 percent.

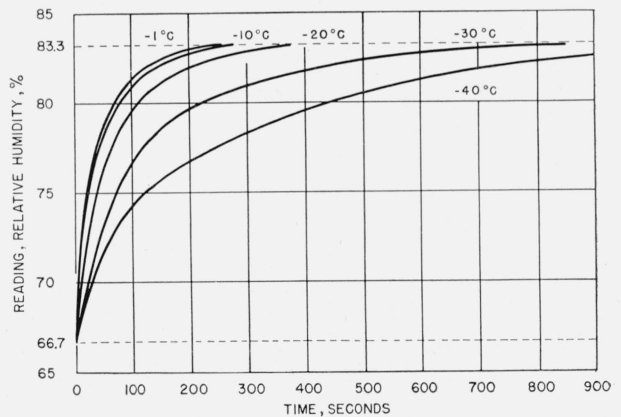


FIGURE 6. Effect of temperature on the time response for a relative humidity change of 66.7 to 83.3 percent.

V. Discussion and Summary

The continued subjection of the electric hygrometer element to the pulsating direct current of the radiosonde circuit has a deleterious effect on its life, primarily because of polarization. Hence in the tests described above, no unit was used more than once or for periods of time exceeding 2 hr. Under these conditions, exposure of a unit to a humidity of 100 percent did not appear to harm its performance. In general, the calibra-

tion and hysteresis characteristics of the hygrometer are satisfactory, except that the range does not extend to low humidities at the lower temperatures. The high lag and the complicated lag behavior of the hygrometer at low temperatures are its major limitations in radiosonde use. With the rates of balloon ascension now employed (1,000 ft/min) and the greater rates contemplated for future use, the lag of this hygrometer introduces a questionable factor in the interpretation of the humidity data.