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Accurate Measurement of Relative Humidity in Field Biology[1]

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Abstract. Measurement of relative humidity has been neglected in most biological field studies partly because of difficulty of accurate measurement. This paper reviews classical relative humidity instruments and modern electrical transducers. Accuracies and operational problems are compared. Finally several approaches to construction of electronic humidity measuring instruments are presented together with a schematic of one circuit which has been field-tested.

INTRODUCTION

Relative humidity, especially that of the microhabitat, is seldom considered in field studies because instruments for measuring it are generally inaccurate or are operationally unsuitable. In connection with a field analysis of the biological importance of relative humidity to bats, the senior author began an investigation of the characteristics and merits of the several instruments and techniques at present available for relative humidity measurement. This paper presents some of the considerations made in choosing the proper type of humidity sensing instrument, a description of several types of transducers, and finally some suggestions for construction of a convenient sensitive ultraportable electronic humidity meter.

Why is it important for biologists to measure relative humidity? The saturation deficiency determines the rate of water loss in many animals. In studying desert hetermyids, Schmidt-Nielsen (1950, 1951) concluded that water conservation dictates a nocturnal activity pattern, while during the day the animal escapes the desert humidity of 15% by remaining underground where humidity may be in the range of 30%. Chew has described water loss correlated with relative humidity in the field mouse *Peromyscus* (Chew, 1955) and the pallid bat, *Anthrozoas* (Chew and White, 1960). Heatwole (1961) quantified desiccation death in salamanders and showed conclusively that distribution of amphibians will be directly related to critical moisture contents of the forest floor litter. Hall (1961) has shown that the little brown bat and the Indiana bat, both myotids, will form hibernating

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clusters in areas of caves with given humidity characteristics. One of the present writers (Henshaw) is attempting to quantify water balance in the same species, and to correlate this with microhabitat conditions.

Classical Instruments

In reviewing possible techniques for humidity sensing in the field and laboratory, a variety of approaches were found to have been used, including (a) thermometric, comparing wet- and dry-bulb temperatures; (b) mechanical, with sensitive elements, e. g., hair or wood fibers; (c) gravimetric, for total water vapor content in a sample; (d) photometric, with dewpoint indicators; and (e) chemical, with color changes or selective absorption of water. All of these techniques have inherent errors which are detailed in Table 1. An expanded discussion of these errors may be found in Wexler and Brombacher (1951).

Electrical Transducers

With the advent of the space age, emphasis among engineers has been placed on miniaturized methods for measurements of physical variables in space capsules and of physiological functions in astronauts. Field biology stands to profit, though the space techniques must be sought out and modified for the particular needs of the field biologist.

Electrical humidity transducers are now produced in a variety of forms (Table 1). Thermistors are incorporated into aspiration psychrometers, and thermocouples have been made small enough that no air movement over the wet-bulb junction is needed; both appear to be unstable. Electrolytic cells passing a current proportional to the electrolysis of water have been developed to measure low humidities. Most recently a bead varying its resistance with the "concentration of dipole moment of water present" has been produced; this must be used with a megohmmeter. Variable resistance units of hygroscopic films of polymers and of hygroscopic salt crystals are now available. These are easily destroyed by immersion and must be frequently recalibrated. Most convenient of transducers investigated appears to be a small plastic wafer sensor with a printed conductive grid[1]. The element varies resistance with water of *adsorption.* In this sensor hysteresis is reduced, less water is removed from the volume of air sampled, and the unit is less likely to be completely destroyed by accidental immersion in water. The time constant is not rapid (about one minute), and accuracy should be in the neighborhood of 1 to 2% RH with individual

[1] Manufactured by El-Tronics, Inc., Warren, Pennsylvania; Sensing Element, No. 2c-B, $12.50.

Table I. Methods of Measuring Relative Humidity

Process	Instrument	Sensing Element	Error	Remarks
Thermometric	Psychrometer	Wet- and Dry-Bulb thermometers	Up to ±10%	Comparison of two thermometers. Thermometers require ventilation of 900 ft/min; (thermistors less; 40 gauge thermocouples none). Requires pure isothermal water. Requires matched thermometers. Large hysteresis. Common field instrument.
Mechanical	Mechanical Hygrometer	Human Hair Goldbeater's skin Wood fibers	At least ±3%	Change in shape geared to indicator. Very long response time. Not accurate below 0° C. "Zero" shifts if humidity not constant. Infrequently used in field; can be miniaturized (see Schmidt-Nielsen, 1950).
Gravimetric	Liquid air trap Dessicant	Accurate balance	Small	Requires weighing alloquots of air; limited by error of balance, if great care taken. Employed only for fundamental calibration. Impractical on field-collected samples.
	Human Hair	Delicate balance	Small	Continuous weighing, calibrated in RH. Not commercially available.
Pressure or Volume	Freeze Trap/Manometer Dessicant/Manometer			Differential pressures before and after removing water. Errors can be appreciable depending on facilities for handling constant gas volumes.
	Critical-Flow-Orifice/Manometer			Sensitive to temperature fluctuations, position changes, etc. Not field instruments.
Chemical	Capillary tubes	H_2SO_4 dilutions		Expose selection of dilutions; note relative change in volumes of drops. Very slow. Accuracy increases with practice. Used in field.
	Papers	$CoBr_2$, $CoCl_2$	Qualitative technique	Color changes matched to chart. Difficult to handle in field, but have been used with some success. Can be made quantitative in laboratory with photometer.
	Ampoules	Organic ketones	±3%	Air pulled through at regulated rate or allowed to equilibrate. Intense color changes. Could be used in the field.
Electrical	Dew point Indicator	Cooled glass surface	Small	Photometer regulates plate temperature, current monitored. Used insensitively with optical reading. Several laboratory versions available.
	Electrolytic Cell		5% (of scale reading)	For low RH. Requires reduced pressure, constant flow.
	"Humistor"	Bead		Must use with megohmeter, therefore real potential error.
	Variable Resistance	Hygroscopic salts Hygroscopic polymer films Under fired clays	to ±1.5%	Easily destroyed by immersion. Calibration unstable. Large hysteresis. Can have very short time constant. Can be incorporated into field instrument.
	Variable Resistance	Adsorption of water	±2%	Less sensitive to immersion. Maximum hysteresis ±2.5%. Calibration stable, but easily destroyed by contaminants, e.g., oil from fingers. Requires AC. Time constant about 1 min.

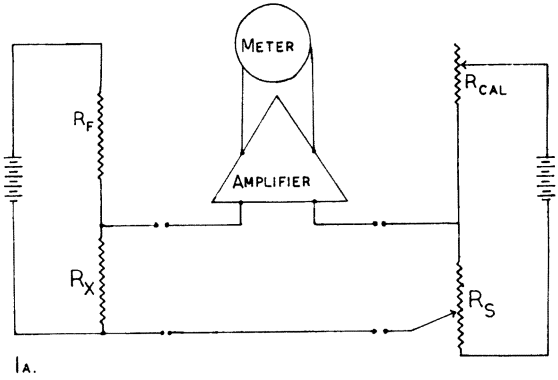
calibration. This element offers high potentiality of development into a research-grade instrument.

Electronic Circuitry

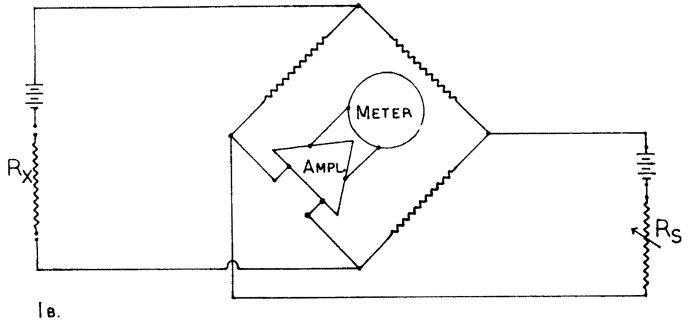
Generally electronics in biological research is a problem of control engineering; this type of engineering attempts to deliver to the observer with as little distortion as possible a true representation of the parameter measured (Donaldson, 1958). By carefully choosing components with respect to transducer output signal, and ambient environmental conditions under which the device must perform, very sensitive instruments which will measure relative humidity with great reliability can be designed.

These humidity sensing instruments will have a generally similar design. The transducer must have an excitation power source, which may be either AC or DC depending upon the requirements of the transducer, and depending upon whether stray voltages may be encountered at the site of observation. The transducer is incorporated into an evaluative circuit whose output is fed into an amplifier to increase sensitivity and thence to a meter for read out. Probably the simpliest circuit that can be made quite sensitive is a *voltage divider* (Fig. 1a), the voltage output of which varies with the parameter and can be measured by using a calibrated voltage divider to produce a bucking voltage. This circuit is particularly good for null indication. If a direct reading instrument is desired, a *differential bridge* (Fig. 1b) may be used since there will be complete electrical isolation of one half from the other. Sensitivity can be great when high voltages are measured because error is the absolute difference between linear components of the input voltages. Thus a most important application of this circuit is suggested; comparison of a relative humidity, such as in an environmental chamber, with a reference relative humidity. Potentially the most sensitive circuit is the *Wheatstone bridge* (Fig. 1c, 2). When it is operated as a null indicator for greatest sensitivity, and because it measures the ratio of resistances of the legs, error will be a constant percentage of the unknown resistance. The Wheatstone bridge is entirely insensitive to inconstancy of excitation voltage when adjusted to its null point. Therefore, if input voltage can not be well regulated, this circuit will probably give superior results. Further, this bridge can be used with AC, thus eliminating possible error due to polarizations of the sensor with DC. (See also Aronson, 1961)

Today electronic measurement in the field is becoming increasingly more convenient. Solid state electronics is beginning to contribute extensively to the miniaturization of laboratory and field instruments. Circuits that would require one cubic foot and



1A.



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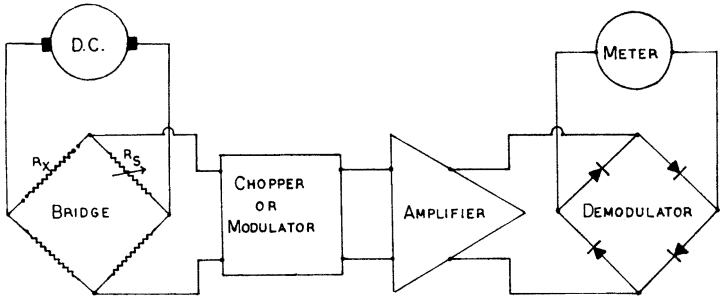

Figure 1. Block Diagrams of Possible Configurations for a Field Humidity sensor. 1a. *Voltage Divider.* A variable voltage is taken off of the variable resistance humidity sensor (R_x) and bucked by a calibrated potential produced by another voltage divider, the slidewire (R_s) of which is calibrated. Current will circulate between the halves, thus through the meter, except at "null." The sensitivity of this device, as well as those below, is directly proportional to the quality of R_s. The calibrated half of the circuit may be zener diode stabilized for further accuracy. 1b. *Differential Bridge.* Though both halves of this circuit are electrically isolated from each order, they both contribute to current flow through the meter except at null. R_s may be a series of fixed resistances so that the meter may read directly variations of R_x about any null. The bridge divides each input current into two components and directly subtracts one of these com-

ponents of the unknown input from the comparable components to the calibrated input. Error will be absolute and independent of the magnitude of the input voltages. 1c. *Wheatstone Bridge.* Whereas the above circuits can measure the parameter as voltage or resistance, the Wheatstone bridge measures resistance ratios of its legs. This is the most flexible circuit, operating either AC or DC. For long-term stability, wire-wound resistors should be used, but temperature dependence of the whole bridge should be quantified. For linearity of output, the legs of the fixed side of the bridge should be 20 or more times the mean value of the variable resistances.

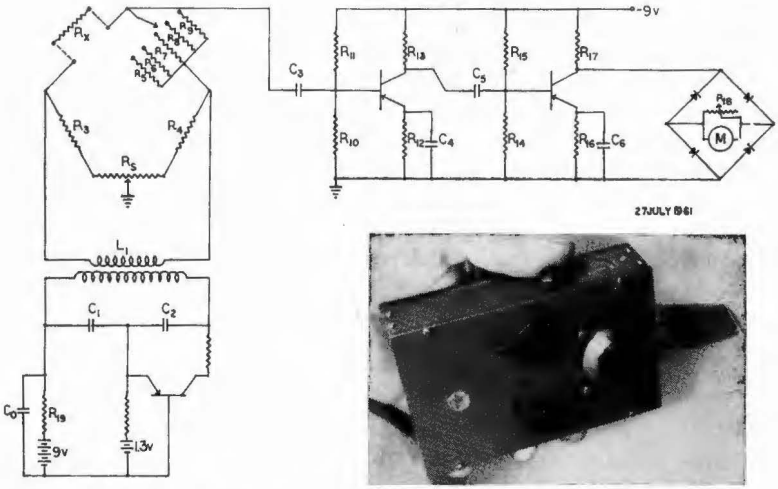

Figure 2. AC Portable Field Humidity Meter. A 600 cps Colpitt's oscillator drives the Wheatstone bridge, the output voltage of which is amplified and applied through a rectifier bridge to a 100 μ amp FM tuning meter. Values for specific components are not given since changes in any components, which might be advantageous in connection with the specific use of the meter, would necessitate changes of many other components. Actual values can be supplied upon request.

an eight-pound battery can now be built into 15 cubic inches. They are relatively free from the fragility of glass electron tubes. If properly compensated they can be very free from temperature effects. Because semiconductors consume so little power, there is a very low battery drainage.

One attempt at perfecting a circuit for field use with miniature transducers is shown in Fig. 2. Here an entirely AC system was used, since the sensor could not be driven with DC. Calibration produced a family of six gently-curving sigmoid curves covering the resistance range from 500 ohms to three megohms with very small variance. The small size and convenience of simple operation suggest a broad applicability of this instrument in biological and meteorological field research and teaching, and in environmental physiological laboratory studies.

Thus in the relatively short time of two decades, field instrumentation has come to the point where the field biologist can ask specific questions about minute fluctuations and maintained differences in microclimatological humidity. In the past, investigators have generally tended to discount the biological

importance of small relative humidity differences primarily because of inability to measure humidity. It appears that in the near future, workers will be able to measure or monitor in the field with sufficient sensitivity to demonstrate any casual relationships between the ambient level of humidity and biological activity.

It is true, however, that increased ability to measure a parameter may lead to overemphasis of the biological importance of that parameter—a most common type of error made by researchers. The investigator is uged to consider carefully whether he needs the added accuracy of sensitive electronic humidity meters. If increased sensitivity is desired, the investigator takes on the added responsibility of equally accurate assessment of the other parameters affecting relative humidity, such as temperature, wind velocity, and biological contribution. With careful recognition of all interrelated variables, the sensitive instruments should prove a valuable asset to field biology.

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