

BUILD AN

Electronic Clinical Thermometer

FAST, EASY-TO-READ AND ACCURATE

There is no mystery to the construction of an electronic clinical thermometer. Besides accuracy and measurement repeatability, the thermistor reaction time is of prime importance. POPULAR ELECTRONICS believes that this project offers the most practical solution to these problems.

THE OLD mercury-glass thermometers that we have all used for so long have many disadvantages. They have to be shaken

down before each use, they're hard to read, and they are all too easily broken. Modern electronic technology now permits us to build a small, portable, self-powered, electronic thermometer that provides a temperature indication in about 30 seconds, is easy to read, and is practically indestructible.

Temperature is sensed by a tiny precision thermistor mounted in a small metal enclosure and connected to the electronics and indicating unit through a length of very flexible cable. The diameter of the thermistor probe is considerably less than that of a

BY J. R. LAUGHLIN

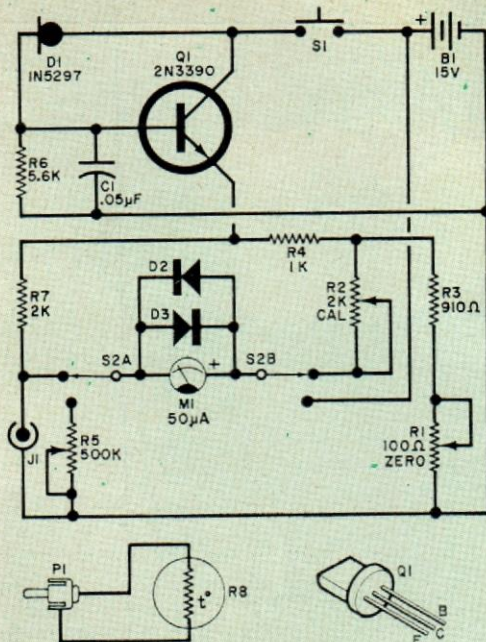


Fig. 1. The thermometer is essentially a Wheatstone bridge powered by a regulated battery power supply. Potentiometer R5 is used to set the meter to full scale with a new battery.

PARTS LIST

- B1—15-volt battery (Eveready 411 or similar)
 C1—0.05-µF, 20-volt ceramic capacitor
 D1—Constant-current diode (Motorola 1N-5297)
 D2, D3—Silicon rectifier diode (1N4001 or similar)
 J1—Phono jack
 M1—50-µA meter (Calectro D1-910 or similar)
 P1—Plug to mate with J1
 Q1—2N3390 transistor
 R1—100-ohm, PC-type trimming potentiometer (Spectrol 84-3-8 or similar)
 R2—2000-ohm, PC-type trimming potentiometer (Spectrol 84-3-8 or similar)
 R3—910-ohm, 5% resistor
 R4—1000-ohm, 5% resistor
 R5—500,000-ohm potentiometer
 R6—5600-ohm, 5% resistor
 R7—2000-ohm, 5% resistor
 R8—300-ohm at 25°C, 1% thermistor (Yellow Springs Instrument 44005 or similar)
 S1—Spst normally open pushbutton switch (Switchcraft 903 or similar)
 S2—Dpdt pushbutton switch (Switchcraft FF-1006 or similar)
 Misc.—Plastic case (4" x 3" x 1½", Calectro J4-725 or similar), length of two-conductor cable (RG-174U, Belden 8216, or similar), press-on type, heat shrinkable tubing, spaghetti tubing, battery clip, wire, etc.

conventional glass clinical thermometer and is thus less uncomfortable for the patient. The probe is difficult to damage by accidentally biting. Its small size also allows it to respond rapidly to temperature changes and the low thermal mass of the housing does not affect the environment of the surround-

ings when temperature is being taken.

Thermistors generally have better long-term stability than thermocouples, and they tend to become more stable with age. In one test, thermistors varied in temperature indication by only 0.03°C per year, over a 12-year period. The resistance value, at any

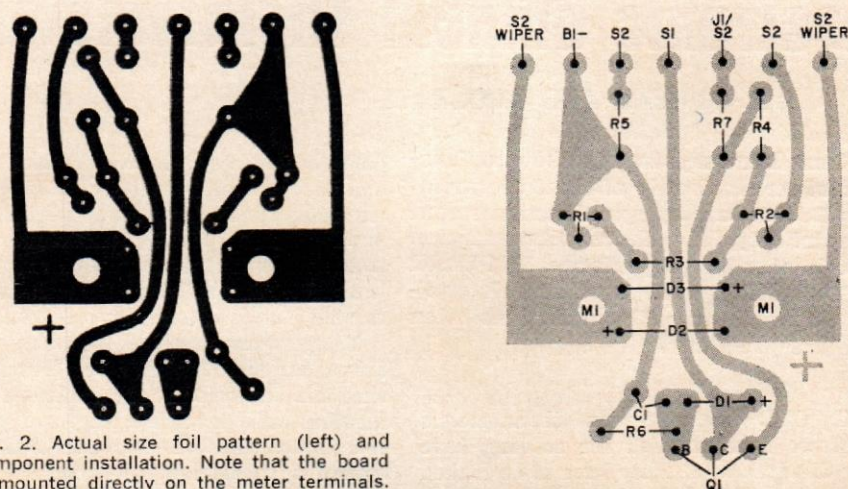
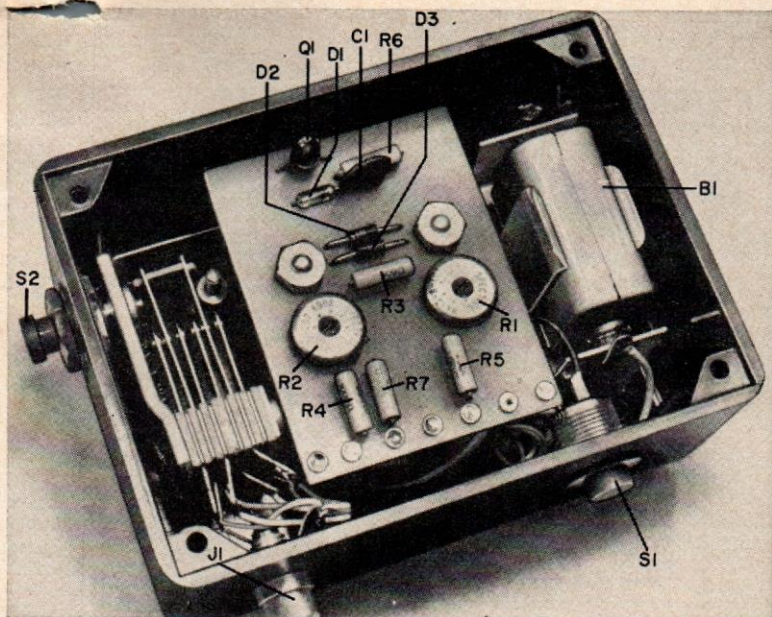


Fig. 2. Actual size foil pattern (left) and component installation. Note that the board is mounted directly on the meter terminals.



Completed thermometer fits in a small plastic case, including battery. Observe that meter is mounted in the "bottom" of case so that removing the cover allows access.

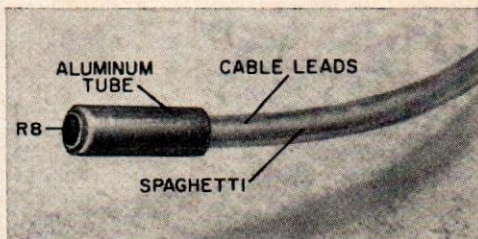
given temperature, for the thermistor used in the thermometer is accurate to less than 1%. This tolerance represents less than 0.18°F variation in temperature indication, which permits the use of any number of probes interchangeably.

Construction. A schematic of the thermometer circuit is shown in Fig. 1. It can be constructed on a small PC board (see Fig. 2) and mounted directly on the meter terminals. The two large holes shown in the foil pattern should be drilled just to fit the meter terminals without sliding around.

Very carefully remove the cover of the meter to expose the scale. Place the meter movement in a dust-free enclosure while modifying the scale. Using a light eraser, remove the numerals and the small division markers, leaving only the six large division markers. Using india ink and ruling equipment, add five matching division markers exactly between the six original markers. This results in ten equal divisions across the scale, each indicating one degree Fahrenheit. Using some form of press-on type, mark the left-hand marker 96. Number every other mark as shown in the photograph. Place a small dot over the 100 mark to indicate the battery cutoff voltage and draw a red line at 98.6 to indicate "normal" temperature. A "TEMP

$^{\circ}\text{F}$ " notation can be added below the scale if desired. Reassemble the scale and meter, taking care that the zero screw engages the proper slot in the movement.

The thermometer can be assembled in a small plastic instrument case measuring $4'' \times 3'' \times 1\frac{1}{2}''$ with the meter mounted on the bottom of the case so that the rest of the assembly can be reached by removing the cover. You can dress up the unit by removing the feet on the bottom of the case and covering it with contact paper. Once the meter is secured, fit the PC board in place and locate the holes for the two switches and probe jack. They must not interfere with the circuit board. Also locate a suitable spot for the battery clip and mount it.



Great care must be used when making up the probe. Use a non-toxic glue to mount the thermistor in the aluminum tube. Observe the Caution on page 78.

To make the probe, obtain approximately two feet of light, flexible two-conductor cable (RG-174U or similar) and terminate one end with a plug that matches the jack on

HOW IT WORKS

The circuit is essentially a Wheatstone Bridge powered by a well-regulated supply. The resistance values for the two legs of the bridge were selected to produce a linear output of desired amplitude for the temperature range covered.

Resistor *R7* is connected in series with the thermistor (*R8*) to form a voltage divider which is one arm of the bridge. The voltage at the junction of these two components is a function of the resistance value of the thermistor, which varies with the temperature. This voltage is applied to the negative terminal of the meter. The other arm of the bridge consists of resistors *R1*, *R3*, and *R4*, with the voltage at the junction of *R3* and *R4* capable of being set to equal exactly the voltage at the meter negative terminal when the thermistor probe is at 96°F. In this condition, no current flows through the meter and it indicates at the left end of the scale.

As the thermistor temperature increases, the voltage at the meter negative terminal goes down with respect to that at the positive terminal which is fixed by the resistor network. A probe temperature of 106°F produces a voltage difference sufficient to deflect the meter full scale. Precise adjustment is made with *R2*.

A well-regulated supply is mandatory for accuracy even though the battery voltage drops with use. The regulator circuit used is superior to a zener regulator in two respects: regulation is better (especially as the battery voltage approaches the cutoff point) and it does not require a minimum current to function with a low dynamic resistance.

Operation of the regulator is based on the constant-current diode. The latter is actually a FET transistor with the gate connected internally to the source. It is carefully selected to obtain the most desirable characteristics. The constant-current diode functions in a manner just the opposite of the zener diode. Instead of maintaining a constant voltage drop, it maintains a constant current for a wide range of impressed voltages. A resistor connected in series with the diode (*R6*) then has a constant voltage across it. In the thermometer, this voltage is 5.6 volts, which is applied to *Q1*. The latter is connected as an emitter follower to supply power to the circuit. The circuit not only provides excellent regulation, but draws only about 1 milliamperes. Capacitor *C1* insures that the transistor will not oscillate, which may be a problem with high-gain transistors.

Diodes *D2* and *D3* protect the meter from excessive voltages when the unit is operated without the probe or with a shorted probe. Voltage across the meter is limited to 0.6 volt.

Resistor *R5* is used to test the battery by causing a full-scale indication for 20 volts. The battery should be replaced when it falls to 8 volts.

the case. Cut a piece of slender aluminum tubing just large enough in diameter to allow the thermistor and connections to be inserted. The edges of the tube should be slightly rounded at each end. If you are using RG-174U cable, trim back the outer plastic cover and the braid for about two inches. The insulated center lead of the cable is connected to one thermistor lead (cut very short and insulated) while the other thermistor lead is brought down the outside and connected to the braid. Slide a length of spaghetti tubing down this pair until it contacts the braid. Use a small piece of heat-shrinkable tubing to secure the spaghetti in place. Insert the thermistor and connections into the aluminum tubing with the aluminum just touching or slightly covering the spaghetti. Flow epoxy into the space between the thermistor and tubing and allow to harden. Use an abrasive paper to make the completed probe smooth.

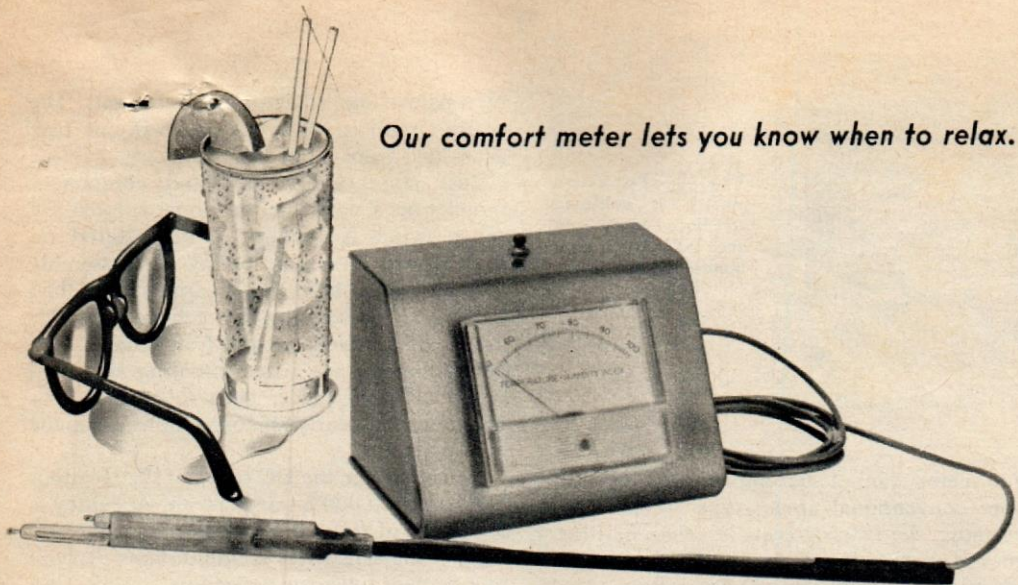
Calibration. To calibrate the electronic thermometer, you will need an accurate bulb-type thermometer. Adjust the meter zero screw until the needle is directly on the 96 mark. Fill a large pot with water and heat to a temperature slightly over 96°F. Remove the heat, place the probe and bulb thermometer in the water, in close proximity, and stir the water continuously. When the water cools to exactly 96°F as indicated by the bulb thermometer, adjust *R1* so that the meter indicates exactly 96. Heat the water to slightly above 106°F, keep stirring and turn off the heat. When the water cools down to exactly 106, adjust *R2* to obtain this indication on the meter. As the water continues to cool, check the mid-scale marks.

CAUTION

Great care must be exercised in fabricating the thermistor probe. A non-toxic epoxy must be used to keep the thermistor in place (particularly at the lead end of the thermistor); and the user must be cautioned not to bite or break the tube while it is in the mouth. Excessive strain should not be placed on the thermistor leads. Some people are allergic to the epoxy that covers the thermistor and can develop a rash when this chemical comes in contact with the sensitive areas within the mouth.

Cleanliness is as important in the use of this thermometer as it is with any other clinical instrument. Always sterilize the probe (with alcohol) before each use.

Our comfort meter lets you know when to relax.



Build Your Own Temperature-Humidity Meter

By
RONALD M. BENREY

IT'S not the heat, it's
the humidity.

The next time you sweat out a sultry summer day, keep in mind that old bromide. Whether you agree or not, it does contain an element of truth. Most people do feel a lot more uncomfortable when both temperature and humidity are high.

Atmospheric humidity plays a major role in your personal comfort. Your body is able to withstand a lot more heat when the humidity is low. Reason is that sweat evaporating on the skin surface is one of the ways your body regulates internal temperature. When the humidity soars, most people feel limp because their bodies cannot lose moisture fast enough.

Tests have shown that 10 percent of us begin to itch when the THI reaches 70. As the THI nudges 75, half of the population starts to complain. And almost everybody is hot and bothered when the THI sweeps over the 80 mark.

The U.S. Weather Service defines the Temperature-Humidity Index according to the following equation:

$$THI = .4 (T_w + T_d) + 15$$

The quantity T_d is the dry bulb temperature, while T_w is the temperature of the wet bulb. At the Weather Bureau, these temperatures are measured on two identical thermom-

eters. One thermometer is equipped with a water-dampened wick hanging from its bulb.

Temperature readings of the wet-bulb thermometer usually are different from that of the dry bulb. As moisture evaporates, it lowers the bulb's temperature. The overall reading of both thermometers is correspondingly lowered. The difference between wet and dry bulb temperatures can be used to determine humidity.

Our temperature-humidity meter won't make you feel any cooler. It will measure the THI in and around your home. Once you know how uncomfortable you are, it's a simple matter adjusting an air conditioner or dehumidifier for best room comfort.

Our meter, circuitwise, is a simple wheatstone bridge. One arm of this bridge contains two thermistors arranged to sample both heat and humidity according to the Weather Service's definition.

In our THI meter, wet and dry thermometers are replaced with thermistors. The thermistors (whose full name is thermal resistor) is the ideal device for the job. As the temperature rises, the thermistor's electrical resistance decreases. This inverse operating characteristic can be made linear over the thermistor's operating range.

Both thermistors are mounted on a probe which is fastened to the end of a fiber or

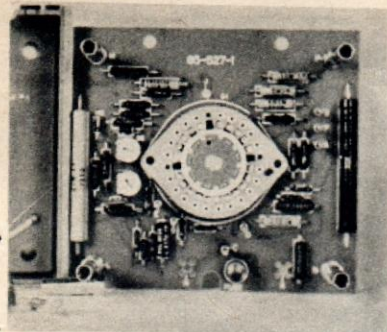


Fig. 2—Function switch is soldered to both front and rear pc boards, then connected via shaft.

multimeter cannot be approached by the more conventional analog-type VOM. Furthermore, the IM-102 costs less than half the amount charged for off-the-shelf digital multimeters having equivalent performance.

As expected, the IM-102 is more challenging to build than its analog sister, the IM-105. After soldering components to the IM-102's printed-circuit board, we discovered that there are several unfilled holes in the board. We don't know why there were empty holes. But the kit works well even with this seeming oversight on the part of Heath.

The Heathkit IM-105 can be built in a couple of hours. Although the Heathkit IM-105 is a state-of-the-art analog meter, it is meant to be constructed by the beginner. There are no surprises for the hobbyist in this kit.

The IM-105 is a ruggedized instrument, using a taut-band meter movement and precision resistors. The movement is protected

by a pair of diodes across the terminals. The entire circuit is protected via an in-line fuse accessible from the front panel.

Just about every part and component mounts on a printed-circuit board. Even the range switch is designed to be soldered via lugs directly to the pc board. The assembly basically consists of two boards sandwiched together. Connections between both boards are made via jacks on the front board, with plugs on the rear. After soldering all board components in place, push the two boards together, and nearly all connections are made automatically.

Sensitivity on the DC range of the Heathkit IM-105 is 20,000 ohms-per-volt. Accuracy is 3 percent of full-scale deflection. On the AC ranges, the sensitivity is 5,000 ohms-per-volt at 4 percent full-scale deflection.

Both DC and AC voltage ranges are 0-2.5, 10, 50, 250, 500, 1,000 and 5,000 volts. Also, a special range enabling you to measure 0-0.25 VDC is available via front-panel jacks.

A DC-blocking output capacitor permits measurements of AC voltages superimposed on DC. A dB scale is provided for measuring audio voltages.

The IM-105 has a total of six DC current ranges and five resistance ranges, with 20 ohms being the center-scale value.

Except for the 1,000- and 5,000-volt scales and the 10-A range, all measurements can be made via two jacks. The range switch selects the proper function so there is no need to worry about plugging the test leads into the

[Continued on page 100]

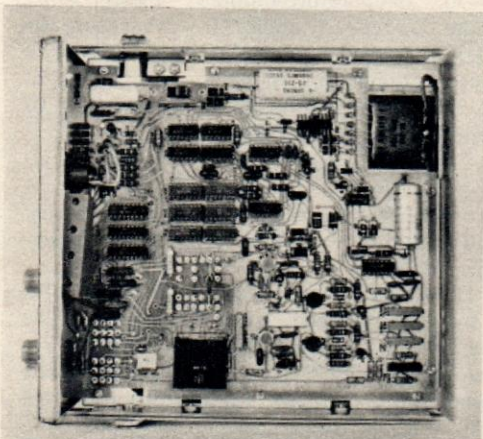


Fig. 3—Top view of IM-102 shows majority of components are mounted to printed-circuit. Note in lower left corner empty holes on board.

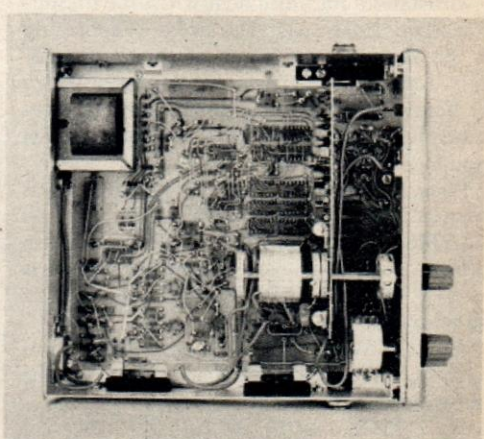


Fig. 4—Bottom view of IM-102 pc board showing range, mode switch, plus AC converter board vertically mounted to 11-deck rotary range switch.

plastic rod. One of the thermistors is made to measure wet bulb temperature by adding a small square of plastic foam dampened with water. The water must be at *room temperature*, otherwise the equation for THI is no longer valid.

To take a THI reading, vigorously wave the rod-mounted probe for a few seconds.

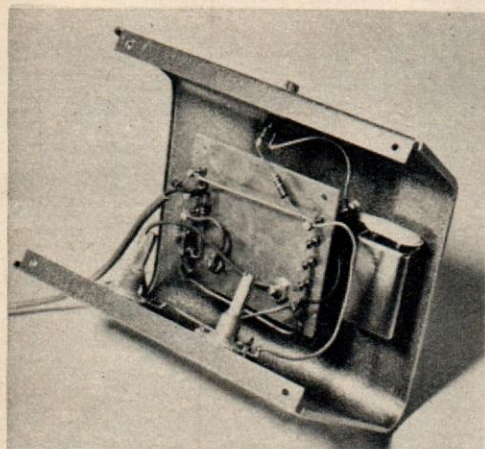


Fig. 1—Except for pots R3, R4 and battery, entire circuit is built on an eight-lug terminal board. Unused lugs are not shown in pictorial for clarity. Terminal board mounts to meter lugs as shown below. B1 is mercury cell.

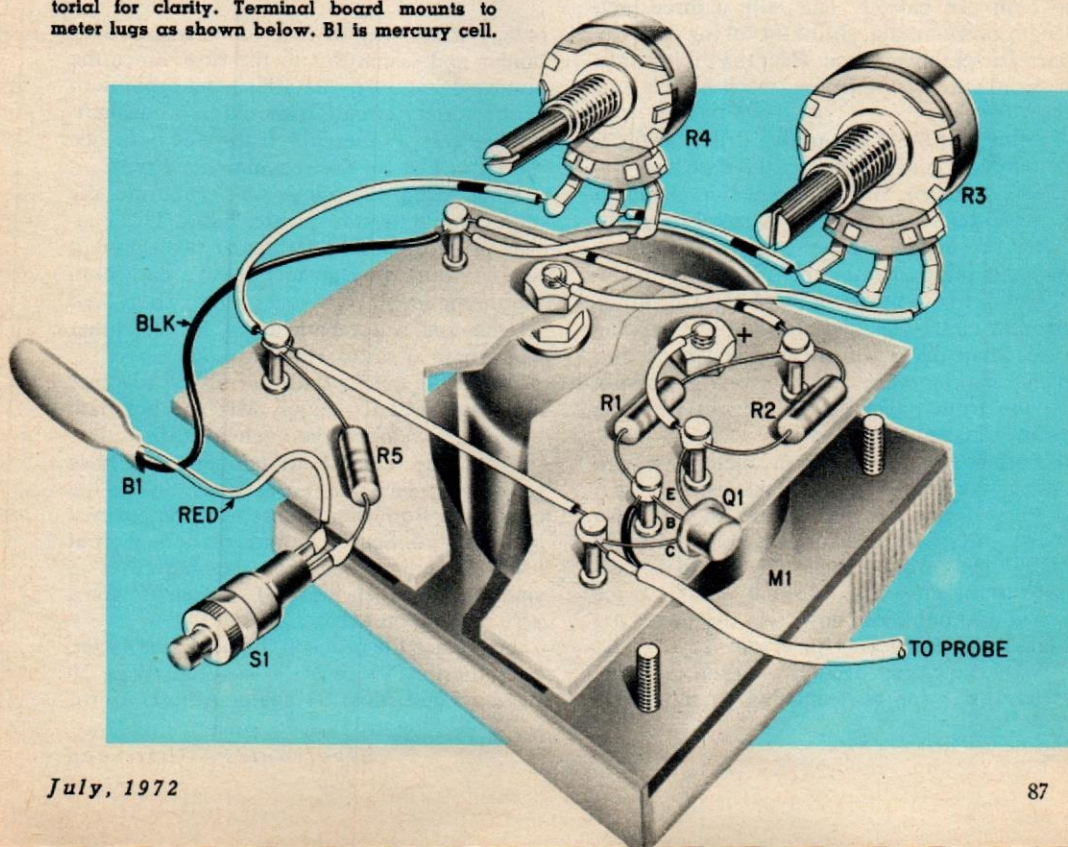
This gives the water a chance to start evaporating. The wet thermistor's temperature will drop below the dry thermistor's.

Potentiometer R3, labelled *High Adjust* in the schematic, determines the meter's final scale reading by multiplying the scale value by 0.4. Similarly, pot R4, labelled *Zero Adjust*, adds 15 points to the scale value. Again, this is done to satisfy the Weather Bureau's THI equation.

Building the THI Meter. The probe body holding both thermistors is made from the plastic barrels of two discarded ballpoint pens. These barrels are held together with a dab of epoxy. Both barrels will later be joined to the plastic rod with a length of heat-shrinkable tubing.

Begin construction by prying the used ink cartridges out of the barrels. Cut an inch or so off one of the barrels. The inside diameter of the barrels will accept plastic-cased, two-conductor cable without squeezing.

Connect the thermistor leads to the ends of two short lengths of cable. Place a piece of spaghetti over one lead of each thermistor to prevent short circuits. Feed the cable through the barrels.



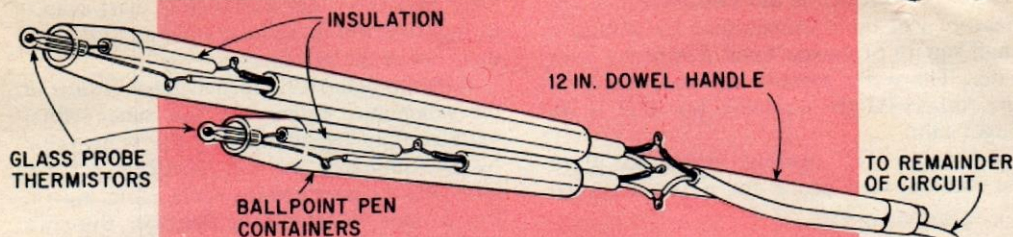


Fig. 2—Tip of thermistor protrudes slightly out of pen container. After thermistors are wired, epoxy them into container. Keep epoxy off tip.

Build Your Own Temperature-Humidity Meter

Cement the thermistors into the tips of the barrels with epoxy. Allow the dark spots within the thermistors to protrude $\frac{1}{4}$ -in. beyond the tip end.

After the thermistors are soldered to their respective lengths of cable, series-connect the two cables together at the base of the barrels. Attach the two remaining leads to a five foot length of two-conductor cable.

Tape one end of a $\frac{1}{4}$ -in. dia. plastic rod to both pen barrels. Then slip a three inch length of $\frac{5}{8}$ -in. dia. shrink-fit tubing over the barrel assembly and rod. Heat the tubing until it shrinks to a form-fit over both barrels and rod.

After you build the probe, drill and file a couple of holes in the meter case for S1. (Press to Read), and a grommet large enough to pass the two-conductor cable through it. After the meter is fastened to the case, remove its plastic front panel.

Cut out (or copy on a piece of card stock) the new meter face and glue it to the existing face. Snap the plastic front panel back into place, making sure that the zero adjust pin on the front panel makes contact with the pointer assembly.

Both pots were glued to the meter case with epoxy. We suggest you do likewise.

Part values are not critical in our THI meter. All of the resistors are soldered to an eight-lug terminal board. The board is fastened to the meter by drilling two holes in the board and bolting it down via the meter lug nuts. See the pictorial for layout.

Wire the circuit by following the pictorial. Battery B1 was also epoxied to the meter

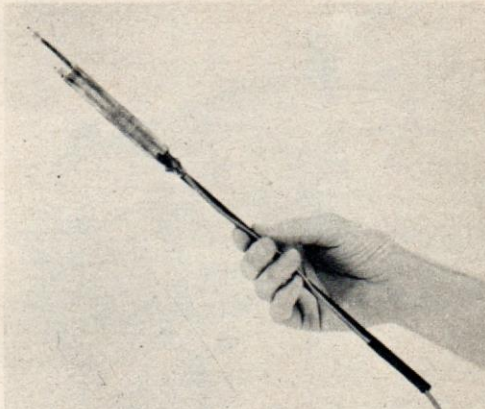


Fig. 3—Entire probe assembly after heat-shrinkable tubing is set in place. Thermistor tip in longer container has sponge placed on it. See text.

case, but we suggest that you buy a battery holder and fasten this to the case. Since the voltage delivered by B1 affects the calibration of the battery circuit, it should be a constant-voltage cell. A mercury battery is best. See the Parts List for the recommended type.

Calibrating the meter. To calibrate the meter, you'll need two water baths. This consists of two glasses of water at two different temperatures. Buy an inexpensive darkroom thermometer at your local photo shop, and set the first water bath at 44°F. The other water bath is set to 100°F.

Make the colder bath by mixing together tap water and ice cubes. Mix the hot bath by heating water on the kitchen stove.

After the water bath temperatures have stabilized, place the probe assembly in the cold bath. Both thermistors must be covered by the liquid. Set R3 to mid rotation. Wait at least 20 seconds for probe temperatures to stabilize, and then press S1. Adjust R4 for a zero reading on M1.

Next, place the probe in the hot bath. Again, both thermistors must be covered. Wait 20 seconds, and press S1 again. Adjust R3 for

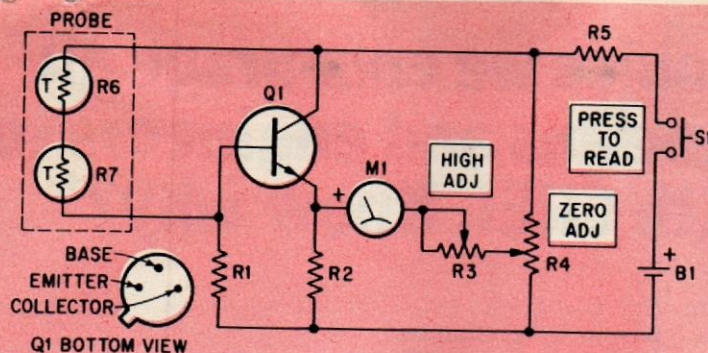


Fig. 4—Schematic of THI meter. Pots R3, R4 are only adjusted during initial calibration procedure. Adjust R3 to read 95 on M1, then adjust R4 to read zero. See text for details.

PARTS LIST

B1—8.4-V mercury battery (Mallory TR146-X or equiv.)
 M1—0.1 ma. DC milliammeter (see note below)
 Q1—Npn transistor (Motorola HEP-50 or equiv.)
 Resistors: ½-watt, 10% unless otherwise indicated
 R1—4,700 ohms
 R2—270 ohms
 R3—5,000-ohm pot.
 R4—500-ohm pot.
 R5—330 ohms

R6, R7—Glass-probe thermistor, 4,000 ohms @ 25 C (Fenwal GB34P2)
 S1—SPST push-button switch
 1—4¼ x 4 x 4-in. aluminum sloping panel meter case (Bud CMA1936 or equiv.)
 1—terminal board
 Misc.—two-conductor cable, epoxy cement, contact cement, fiber or plastic rod (see text), ⅜-in. shrink-fit tubing.
 Note: M1 available from Allied Industrial Electronics, 2400 W. Washington Blvd., Chicago, Ill. 60612. Part number 701-0020 \$17.40 plus postage.

a meter reading of 95.

Before using the THI meter, make sure that thermistor elements R6 and R7 are at the same temperature. The sponge pad should be dry before it is dampened for best instrument accuracy.

As mentioned earlier, our THI meter alone can't make you more comfortable. That job is up to your air conditioner or dehumidifier. If the air conditioner is working properly, room THI should drop whenever it's operating.

Some people don't like the effect of air conditioning and rely upon dehumidification instead. Again, adjust the dehumidifier until the THI meter registers a steady 60-65 reading.

Room comfort is not only affected by the size and efficiency of an air conditioner or dehumidifier but also the number of windows, outside temperature and room insulation. A room facing north in a temperate climate will probably be cooler than one having windows facing south. Thus, a room's total heat load fluctuates constantly.

To use the temperature-humidity index meter, dampen a foam pad with water and slip it over the thermistor cemented to the longer of the two pen barrels. Wave the probe assembly vigorously for about 30 seconds. Press S1, and take your reading.

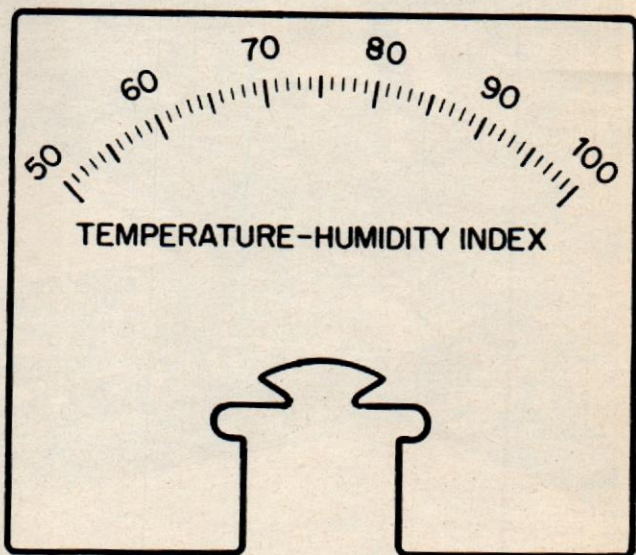
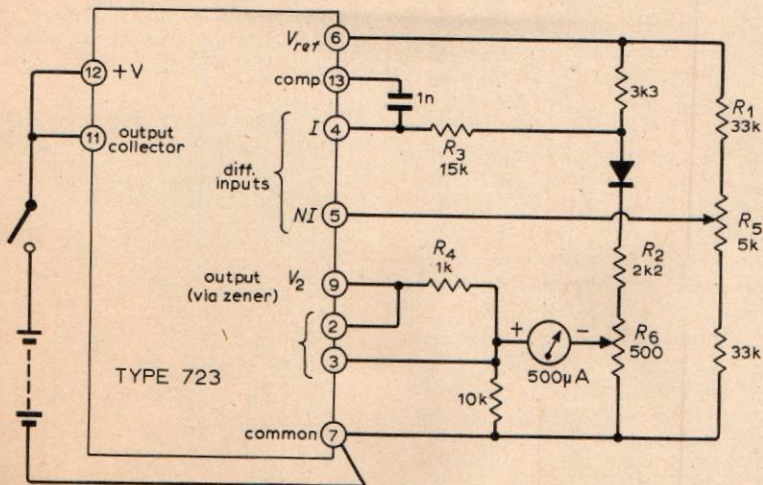


Fig. 5—Cut out meter face and paste it over original dial.

Electronic thermometer uses i.c.



The surface-temperature thermometer using discrete components described by L. Nelson-Jones (*Wireless World* vol.75 1969 pp.180-3) measures the forward voltage drop of a silicon diode, which varies essentially linearly with temperature. A circuit to do this can be constructed very easily using the 723 integrated circuit voltage regulator. Compared with the original circuit, this offers:

- independence of meter resistance — no need for thermistor compensation
- use of a less-sensitive meter without affecting diode current
- lower current consumption — about 3mA.

If the meter current is set to zero at 0°C

by R_3 , at higher temperatures the regulator amplifier forces current through the meter and the lower part of R_6 until the potential difference produced in the latter equals the decrease in diode voltage and rebalances the bridge. Thus R_6 controls the temperature span. Resistor R_1 may need adjustment for some diodes; R_2 raises the input voltage to the differential amplifier — the makers specify 2V; R_3 approximately equalizes the source resistance of the two inputs; and R_4 , with the internal current-limiting circuit, protects the meter from severe overload.

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