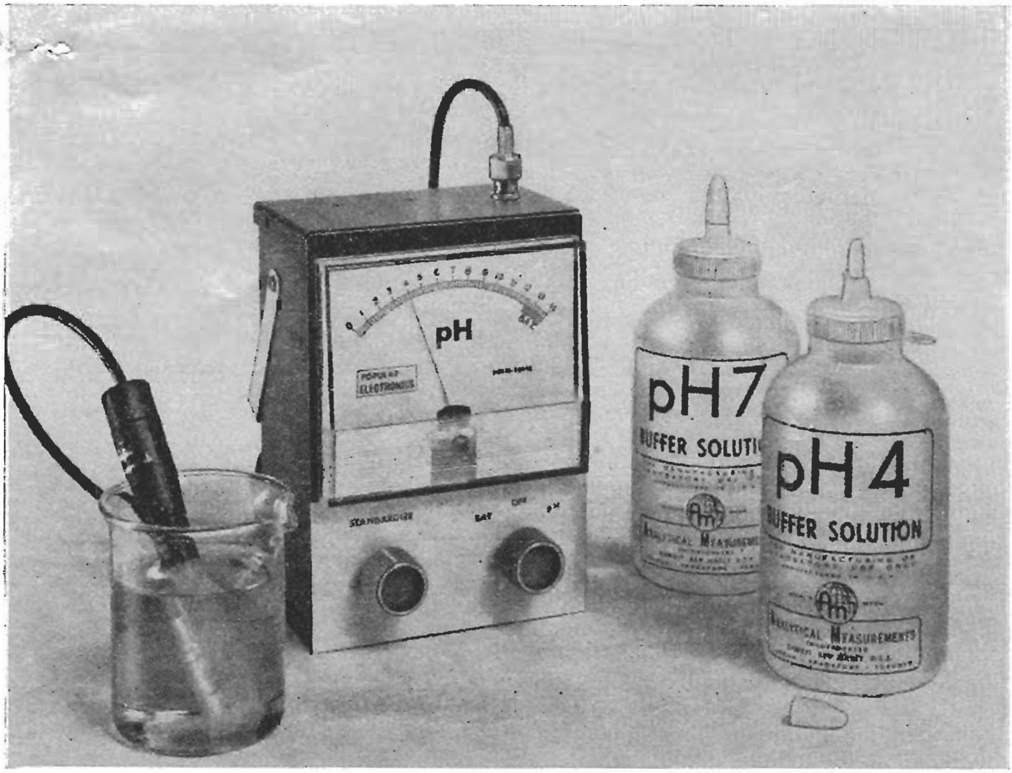


solid-state pH meter

electronics IN THE chemistry LAB

ACID OR ALKALINE? HOW MUCH? THIS LOW-COST, HIGHLY ACCURATE PROJECT HAS DIRECT READOUT

COVER STORY BY R. C. DENNISON

THE HIGH COST of pH meters ($100 to $500) has ruled out their use in many small schools and laboratories. Now, through the use of low-cost metal-oxide-semiconductor field-effect transistors (MOSFET's), it is possible for any amateur scientist to have his own high-quality pH meter. It can be built for about $26. The recommended pH probe (see Parts List) is specially designed for student use with its delicate glass electrode surrounded by a protective polyethylene shield. Its price of $20 is about half that of most other probes.

The circuit (see Fig. 1) uses two MOSFET's in a differential-amplifier configuration. An advantage of this symmetrical circuit is that temperature and drain-voltage variations tend to affect the currents in *Q1* and *Q2* equally and are effectively cancelled in their effect on the meter reading. Stability is further improved by the use of a zener diode (*D1*) to regulate the drain voltage.

A portion of the meter scale (between pH 12.5 and pH 14) is colored green and is used to determine whether or not the battery is in good condition. With the function switch (*S1*) in the BAT position, only the battery with normal loading is connected to the meter. The battery's condition is good if the meter

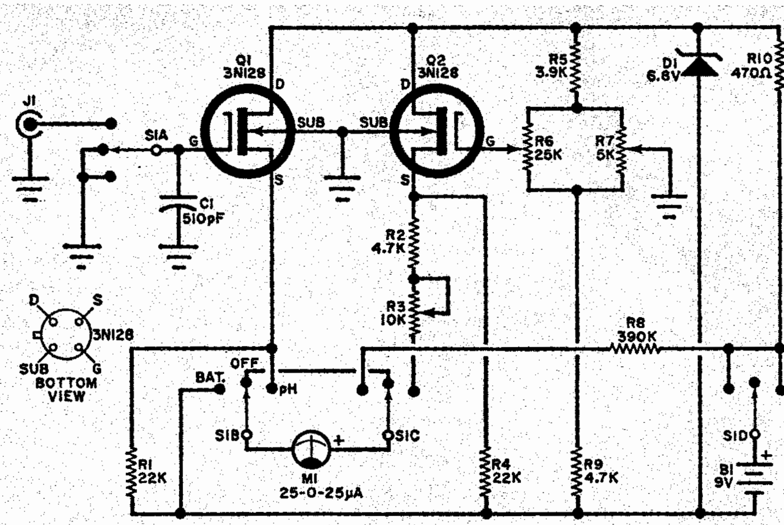


Fig. 1. The symmetrical configuration of the differential-amplifier circuit cancels errors caused by temperature and drain-voltage variations in MOSFET'S.

PARTS LIST

B1—9-volt battery
C1—510-pF, dipped mica capacitor
D1—6.8-volt, 400-mW zener diode (TI 1N3514 or similar)
J1—BNC jack, UG-1094/U
M1—25-0-25 microammeter, 4½-inch
Q1, Q2—3N128 n-channel MOSFET (RCA)
R1, R4—22,000-ohm
R2, R9—4,700-ohm
R5—3,900-ohm
R8—390,000-ohm
R10—470-ohm
(All resistors ½-watt)
R3—10,000-ohm, trimmer potentiometer, (Mallory MTC14L1 or similar)
R6—25,000-ohm, ½-watt linear potentiometer
R7—5,000-ohm, trimmer potentiometer (Mallory MTC53L1 or similar)
S1—Five-pole, three-position, non-shorting ceramic switch (Centralab PA-2015) (Do not substitute.) Note only four of the poles are used.
Misc.—3" x 5" x 7" metal cabinet (Bud CU-3008-A or similar), aluminum handle, thumbscrew, ¼" metal spacers, knobs, battery connector, screws, nuts, wire, solder, Print-Kote, etc.
The following items are available from Analytical Measurements, Inc., 31 Willow St., Chatham, N. J. 07928: pH probe with BNC fitting—$20; KCl refill solution for pH probe, 4-oz bottle—$1; buffer kit, (3) 500-ml plastic bottles, 3 pkgs each of powdered buffer salts, 4, 7, 9 pH—$6. Include postage & N. J. tax.

reading is in the green portion of the scale.

When *S1* is in the OFF position, the meter is shunted to protect the sensitive movement during transportation. All pH measurements are made with *S1* in the pH position.

Construction. The transistors, resistors, and other small components are mounted on a printed-circuit board shown full size in Fig. 2. Use glass-epoxy-base copper-clad board instead of the ordinary paper-phenolic type to maintain high input resistance in humid weather. After the board is etched, wash it at least ½ hour in running water; then dry it thoroughly and drill it. Install all components, except the transistors, but including one circuit jumper and two temporary jumpers as shown in Fig. 3. A finished board is shown in Fig. 4.

MOSFET's are easily damaged by static electric charges unless certain precautions are observed. They are shipped with their leads inserted in a metal ferrule. Do not remove this ferrule until you are ready to solder the transistor to the board. Solder all the other components in place first. Make sure that the temporary wire jumpers are in place as shown in Fig. 3. These jumpers protect the MOSFET's during assembly and wiring. Now remove the ferrules and bend the MOSFET leads to fit into the holes in the board. Get the soldering iron hot but

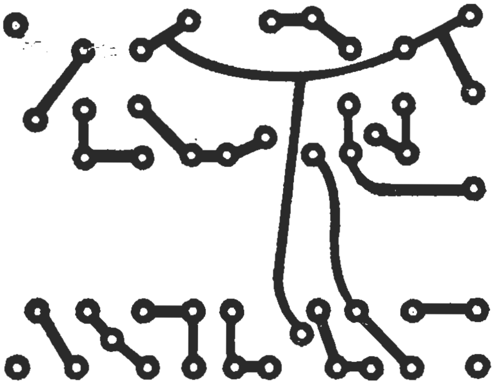


Fig. 2. Use best-quality copper-clad glass-epoxy-base board to maintain high input resistance of pH meter.

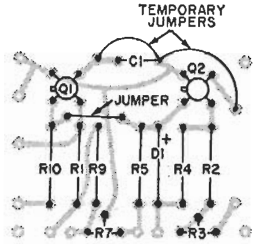


Fig. 3. To protect MOSFET's against damage, connect temporary jumpers as shown until meter is fully assembled.

WHAT IS pH?

An acid is a substance that yields hydrogen ions (H^+) when dissolved in water. Actually, each hydrogen ion attaches itself to a molecule of water to form a hydronium ion (H_3O^+). The concentration of hydronium ions in a solution is a measure of the strength of the acid.

Chemists usually measure concentration in moles per liter. For example, 0.1 molar hydrochloric acid contains 3.65 grams (0.1 mole) of hydrogen chloride in one liter of solution because the molecular weight of hydrogen chloride is 36.5. Since HCl tends to dissociate completely into ions in solution, the concentration of hydronium ions in this solution would also be 0.1 mole per liter. Some substances dissociate only slightly. Thus, in acetic acid, only 1.36% of the molecules in a 0.1 molar solution dissociate. Therefore, the hydronium ion concentration would be 0.00136 moles per liter.

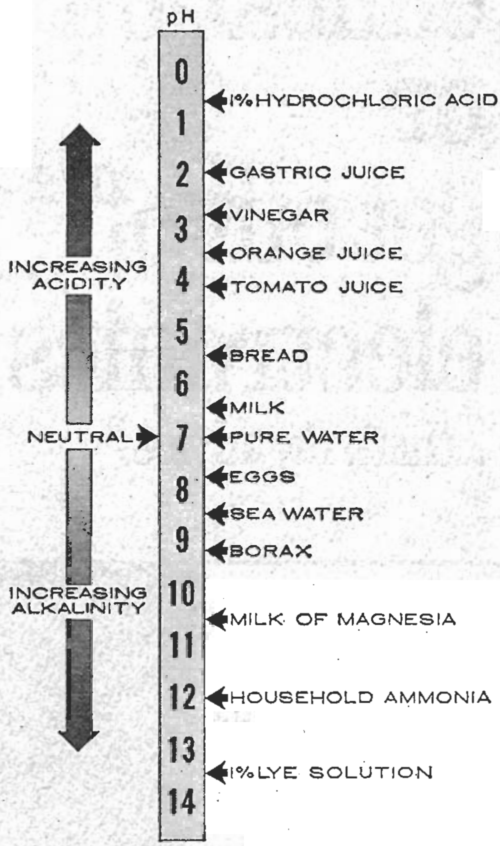
To avoid the use of such small, inconvenient numbers, it is customary to express the hydronium-ion concentration in terms of pH values defined by the equation

$$pH = \log (1/H_3O^+)$$

where H_3O^+ is the hydronium ion concentration in moles per liter. Thus, in the examples above, the 0.1 molar solutions of hydrochloric and acetic acid have pH values of 1.0 and 2.87 respectively.

The pH scale is a logarithmic scale similar to that of the decibel. Each 10-fold change in acidity changes the pH value one unit. The pH values of some common substances are shown on the accompanying scale. From this, we see that orange juice is 1000 times more acidic than milk. Note that the scale runs from 0 to 14. Pure water is neutral with a pH of 7. Lower pH values indicate an acidic substance while higher values indicate alkalinity.

Many chemical processes are greatly affected by small changes in the degree of acidity or pH value. Some examples are the speed of chemical reactions, the growth of micro-organisms, the quality of electroplated deposits, the polymerization of synthetic rubber, the growth of plants and the tendency of jellies to gel. Thus the accurate measurement of pH assumes great importance in chemical laboratories, medical and biological research, food preparation, agriculture, and industrial quality control. Often, pH instrumentation is used in continuous closed-loop (feedback) systems in process control.



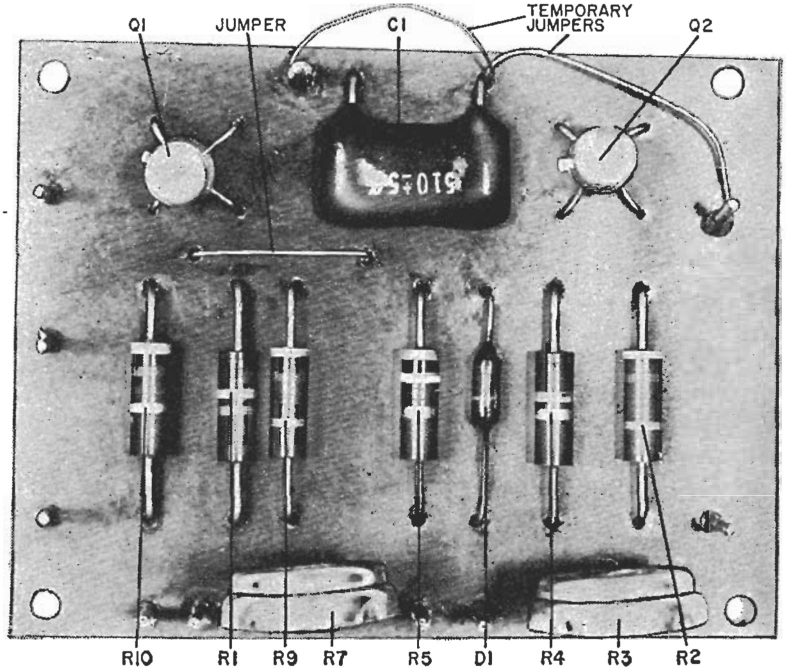


Fig. 4. Make sure that temporary jumpers are in place before soldering the MOSFET's into the circuit. When handling Q1 and Q2, and when mounting them on circuit board, do not remove the shorting rings. See text for precautions to take while soldering.

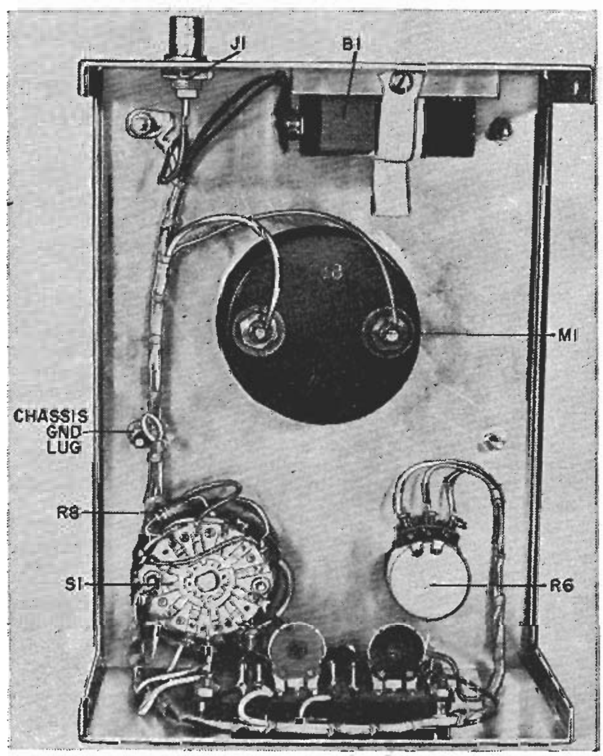


Fig. 5. After components and circuit board are mounted in their respective locations on the metal box, wire them together. To obtain a neat, professional appearance, use lacing cord to bundle the wires into harness configuration as shown in this photo.

then unplug it while soldering the transistors to the board. You may have to re-heat the iron to get all of the connections made, but be sure to have it unplugged while attaching the transistors. Failure to do so may result in permanent damage to the gates of the MOSFET's.

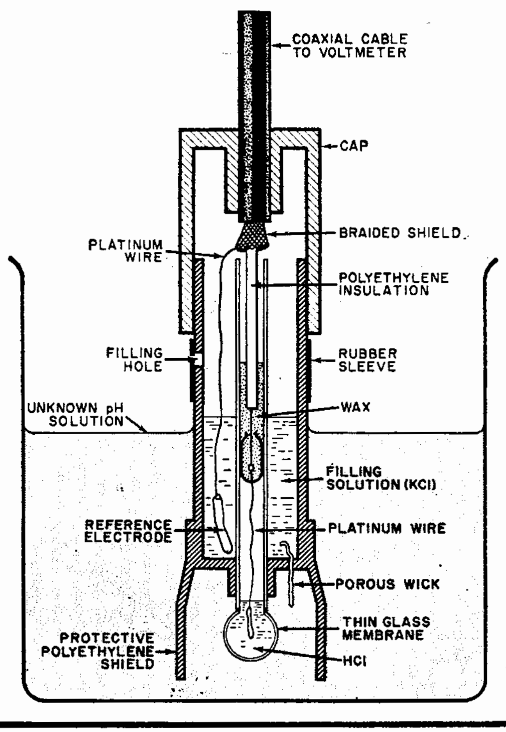
As in all work with printed circuits and semiconductors, use a low-wattage iron (25 to 35 watts) to avoid damage due to excessive temperatures. Remove all flux from both sides of the board using alcohol and a clean cloth. Dry the board thoroughly and then coat both sides with a silicone resin such as GC Print Kote to moisture-proof the board.

Mount potentiometer *R6*, switch *S1*, and BNC connector *J1* to the front of the chassis as shown in Fig. 5. The battery is supported on a 2″ × 1″ × ¼″ block of plastic by a piece of ⅜″-wide dressmaker's elastic secured to the plastic with screws. The elastic band holds the battery securely, and the plastic base insulates the battery from the metal chassis.

The original scale of the meter must be removed and replaced with a linear scale calibrated from zero to 14 with 7 in the middle. Subdivide each major segment into five minor segments. (See photo of meter front panel.) The section between 12.5 and 14 should be colored green for the battery test described earlier.

Mount the board to the bottom of the chassis using ¼″ metal spacers and appropriate hardware. Complete the wiring using only high-quality wire. If the wire from *J1* to *S1* is to be laced with the other wiring, it should have teflon, polystyrene, or polyethylene insulation. If the wires are laced, coat the wire harness with low-loss coil dope to exclude moisture. Do not substitute a phenolic switch for the ceramic switch specified. Keep all insulation clean and free of grease and soldering flux. A small packet of silica-gel desiccant may be kept inside the pH meter to remove the last traces of moisture.

The handle is made from a piece of ½″ × ¹⁄₁₆″ aluminum and may be secured in any position by means of a thumbscrew on one side. The thumbscrew engages a small piece of threaded brass which is held in place by flat-headed screws. The other side of the handle is fastened to the case by a free-turning



HOW pH IS MEASURED

Every schoolboy knows that litmus paper can be used to determine whether a substance is an acid or a base. Other chemical indicators which change color at various pH values are also available. However, the modern way to measure pH is by means of the electronic pH meter. Its operation is based on the use of a glass electrode and a reference electrode, often combined into a single probe similar to that shown in the diagram.

The thin glass membrane is permeated by the charge-carrying hydrogen ions, the number of ions that pass through the membrane being determined by their concentration in the liquid being tested. Therefore, when the probe is placed in a solution, it develops a voltage at its terminals which is proportional to the pH of the solution.

Because the resistance of the glass electrode may be as high as 200 megohms, the voltmeter portion of the pH meter must have a very high input resistance. Since some MOSFET's have input resistances of 10 million megohms or more, they may be used to make an excellent low-cost pH meter.

screw. This lockable handle can be used to support the pH meter in a tilted position to make it easier to use and read.

Adjustment and Calibration. After all wiring has been carefully checked, snip out the jumper associated with *Q2*. Rotate the STANDARDIZE control, *R6*, and the zero-adjust potentiometer, *R7*, to their mid-positions and set the calibrate potentiometer, *R3*, to maximum resistance. With *S1* set to OFF, install the battery. Put *S1* in the BAT position and check that the meter deflects nearly full scale (within the green region). Turn *S1* to the pH position and rotate the zero-adjust potentiometer to bring the meter pointer to center scale (pH7). Turn *S1* off and snip out the other temporary jumper (around *C1*). A note of caution: to protect the input MOSFET, *Q1*, switch *S1* shunts the gate to ground in both the OFF and BAT positions. Do not turn the switch to the pH position unless the pH probe is connected and immersed in a solution. (An exception to this rule occurs during calibration. Follow the calibration instructions below carefully to avoid damaging *Q1*.)

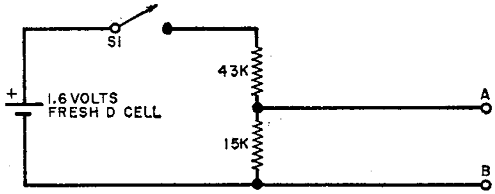


Fig. 6. The outboard calibration circuit for pH meter must be assembled around new, fresh D cell.

The meter is calibrated using the circuit shown in Fig. 6. Make sure the meter is off while making the following connections. Connect point B to the metal case of the meter and connect point A to the center terminal of the meter input jack, *J1*. Alligator-type clips are ideal for these test leads. Place the function switch on pH and adjust the STANDARDIZE control if necessary to make the meter read pH7. Close switch *S1* on the calibration circuit and the meter should deflect toward the left. Adjust calibration potentiometer *R3* to make the meter indicate 0 pH. Turn the function switch to OFF and disconnect the test circuit. The pH meter is now calibrated for use with solutions having a temperature of 25°C, which is typical room temperature. A formula to be given later can be used to correct the meter reading for temperatures other than 25°C.

Standardizing Buffers. Before the pH of a solution can be measured, it is necessary to standardize the meter. This is done by dipping the pH probe into a solution of known pH and rotating the STANDARDIZE control until the meter indicates the known pH. After the meter is thus standardized, the probe is rinsed in distilled water, wiped dry with a lint-free cloth, and then placed in the solution whose pH is to be measured. These standardizing solutions are called *buffer* solutions and are selected on the basis of their tendency to maintain a constant pH value in spite of small amounts of contamination or dilution during use. You can buy buffer solutions at a reasonable cost or you can make your own. For greatest accuracy, choose a buffer whose pH is close to that of the unknown.

- Buffer No. 1. pH = 4.01. Dissolve 5.1 grams of potassium hydrogen phthalate in sufficient water to make 500 milliliters of solution.
- Buffer No. 2. pH = 6.86. Dissolve 1.7 grams of potassium dihydrogen phosphate and 1.77 grams of anhydrous disodium hydrogen phosphate in sufficient water to make 500 milliliters of solution.
- Buffer No. 3. pH = 9.18. Dissolve 1.85 grams of sodium tetraborate decahydrate in sufficient water to make 500 milliliters of solution.

Use distilled water and keep the buffer in a tightly stoppered bottle. A small crystal of thymol may be added to the bottle to inhibit the growth of mold.

Temperature Compensation. Assume the temperature of the standardizing buffer and the unknown is T (in degress centigrade). The error in instrument reading, to be substracted from the indicated pH, is then

$$\text{pH error} = \frac{(T-25)\ (pH_r - pH_s)}{T + 273}$$

where pH_r is the instrument reading and pH_s is the pH of the buffer. —30—