RADIO — ELECTRONICS

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HUGO GERNSBACK, *Editor*

formerly RADIO CRAFT

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NEW ELECTRET DEVELOPMENTS

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LATEST IN RADIO — ELECTRONICS — TELEVISION


What the electret looks like.

Improved ELECTRETS

By EDWARD PADGETT

New compounds produce electrets with better stability and higher surface charge


The author's sister engaged in removing from the mold a new electret just out of the oven.

INTERESTING opportunities for the electronics researcher lie in the development of improved electrets. An electret is a mixture of certain dielectric materials which has been cooled to solidification in a strong electric field. At room temperature one electret surface has a negative electric charge and the other surface is charged positively. If the electret is covered with a metal-foil "keeper," these electric charges do not decay appreciably with the passage of time.

The first workers to make electrets were Mototaro Eguchi of the Higher Naval College of Tokyo and Andrew Gemant of England and the United States, who repeated Eguchi's experiments some years later. Victor Laughter published the first photographs of electrets in this hemisphere (RADIO-CRAFT, May, 1948). Andrew Gemant holds British patents in which electrets are used in experimental electrometers and transformers. The Japanese, however, were the first to find extensive practical uses for the electret. Microphones captured from the Japanese during the war used electrets to furnish polarizing voltages.

Scientists report that Carnauba wax (which comes from a Brazilian palm tree) is an essential ingredient in the preparation of wax electrets. Carnauba wax is a unique mixture of high-melting-point *esters*. (Esters—as well as water—are formed when organic acids and alcohols react. They are somewhat like salts, but react more slowly than salts.) The best grade of the wax is No. 1 yellow, or No. 1 North Country Carnauba wax. It is hard, brittle, and cracks easily. This cracking may be eliminated by adding suitable *extenders* such as paraffin wax to the Carnauba.

Experiments performed by the writer at New York University indicate that

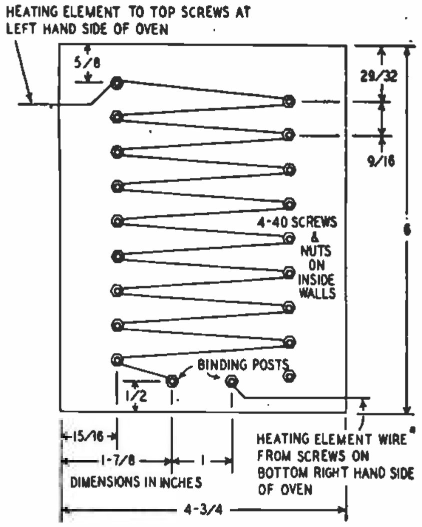
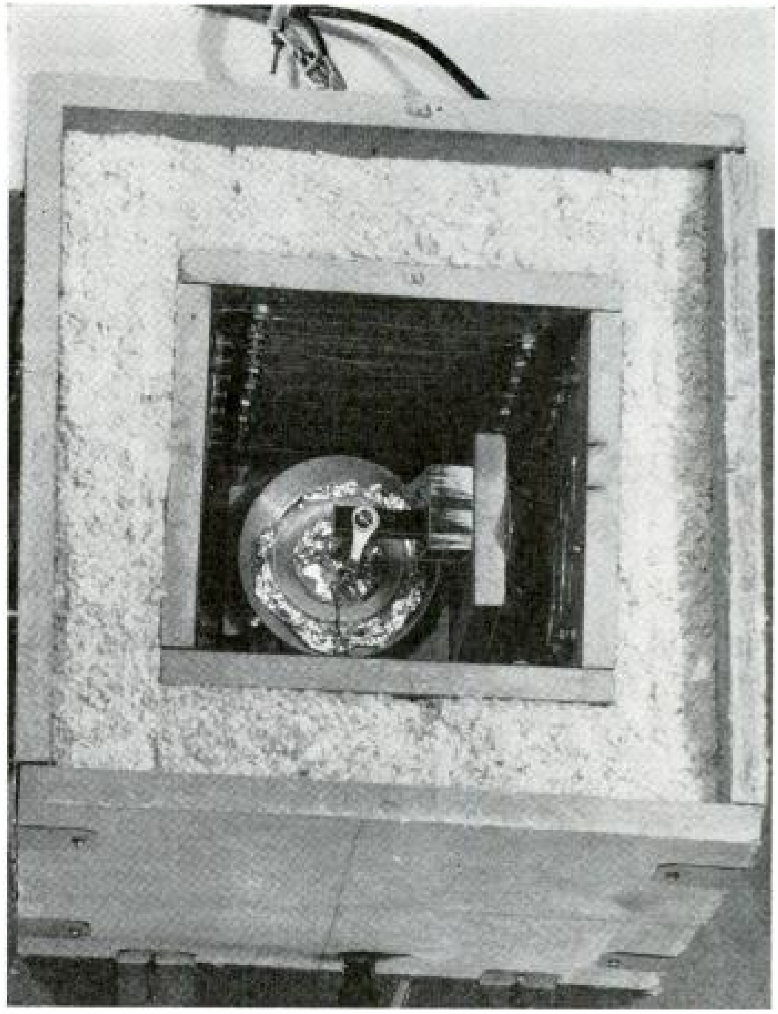


Diagram of heating wires shown in the photo.



Insulation in the author's oven allowed studies of prolonged cooling effects.

electret properties are associated with the polar groups (i.e., -OH, -COOH) that occur in certain substances. Paraffin waxes contain no polar groups and, in themselves, do not form electrets. Carnauba wax contains polar groups and forms electrets.

Early workers made electrets from a mixture of Carnauba wax, rosin, and beeswax. This mixture is not satisfactory for several reasons. For instance, beeswax is relatively soft and so complex, physically and chemically, that it is difficult to study. Rosin is unstable, is subject to decomposition by light, and precipitates out of the wax mixture.

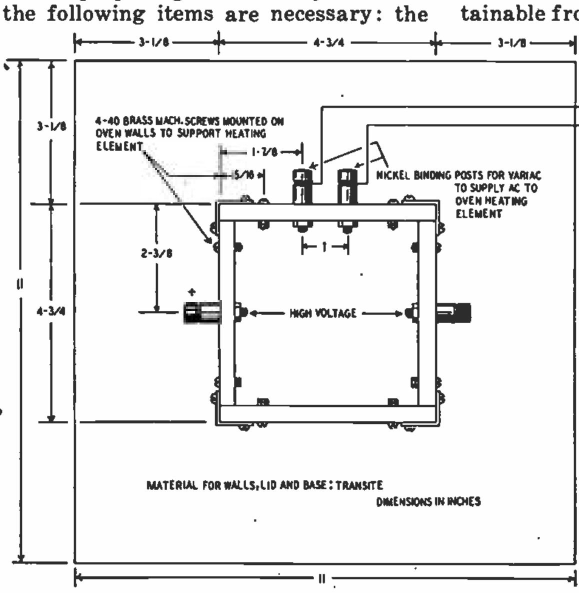
The writer has made electrets of better stability, and with higher surface charge, from equal parts of Carnauba wax and Hercules hydrogenated rosin (Staybelite resin). Hydrogenation of rosin eliminates the difficulties mentioned above. Splendid semiplastic electrets can be made from 45% Carnauba wax, 45% hydrogenated rosin, and 10% ethyl cellulose.

Electret-making apparatus

For preparing satisfactory electrets the following items are necessary: the dielectrics mentioned; metal foil (.001-inch thick); a high-voltage power supply; a metallic mold (really a parallel-plate disc capacitor) to hold the molten dielectric; and an oven to house the mold. An oven is used because controlled cooling of the dielectric makes better electrets. From 1 to 2 hours is the best cooling time for the mixtures described.

An insulated oven can be made from sheets of ⅜-inch-thick Transite (obtainable from lumber yards or hardware stores). Transite can be cut with a small, heavy-bladed hacksaw. The Transite slabs are held together with brass 4-40 machine screws and home-made brass brackets (right angles). One of the photographs shows an oven lined with flake asbestos. The lining gave sufficient insulation to study prolonged cooling of the dielectric. The asbestos is not necessary.

A suitable oven for electret making is shown in Fig 1. The inside dimensions



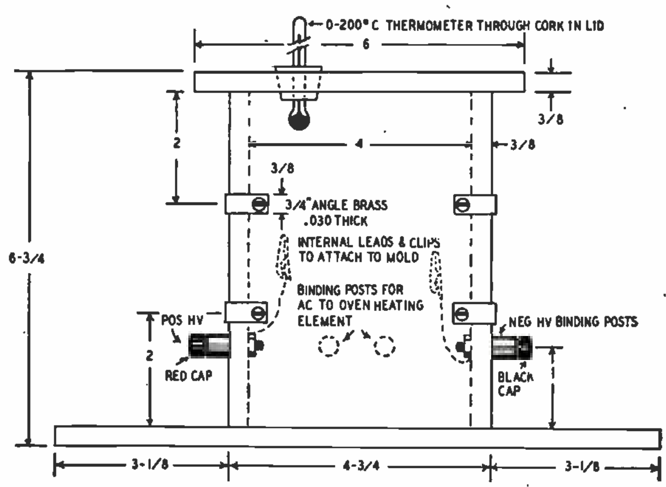


Fig. 1—Top and side views of an oven suitable for making electrets.

Fig. 2—Transite stand holds the mold, covered with tinfoil. Stand is placed in the oven.

of the oven cavity are 4 x 4 x 6 inches. Two colored binding posts for application of high voltages to the mold are mounted in opposite oven walls. From these posts short lengths of No. 18 hookup wire terminated with small clips pass into the oven cavity. Connecting the clips to the mold permits application of the high-voltage field to the dielectric inside.

One of the remaining oven walls contains two nickel-plated binding posts for the heating element of No. 28 Nichrome wire (4.25 ohms per foot). The element may contain from 25 to 50 feet of resistance wire, depending on the number of screws in the oven walls. Two rows of staggered holes are drilled in each wall. Machine screws and nuts are inserted, the nuts facing into the cavity. Start at one nickel binding post and wind the Nichrome wire in zig-zag fashion over the screws on the inside cavity. Terminate the wire at the other nickel binding post. Washers prevent cutting the Nichrome wire when tightening the nuts to hold the wire in place. Commercial a.c. is applied to the heating element through a General Radio V5-M-T Variac. Oven temperatures are read from a thermometer (0 to 200 degrees C) mounted in a cork in the oven lid. Simply lift off the lid to remove it from the oven. In the lab thermocouples and a Leeds and Northrup recording potentiometer were used to obtain temperature readings.

The mold which holds the dielectric is a parallel-plate capacitor. The lower electrode is a circular, rimmed brass cup with an inside diameter of 40 mm and an inside depth of 13 mm. Cup walls are 1.6 mm thick. The top electrode is a flat brass disc 25 mm in diameter and 2 mm thick, silver-soldered to a brass rod ¼ inch in diameter and 1½ inches long. Both electrodes are lined with .001-inch aluminum foil. The rod of the upper electrode is screwed to a bakelite insulator attached to a Transite stand (see Fig. 2). A slit in the back of the stand allows adjustment of the vertical distance between electrodes. The Transite stand is 4¾ inches high and 2⅜ inches wide, and fits nicely into the oven cavity.

Fig. 3 shows the circuit of the high-voltage power supply used to apply a strong electric field to the dielectric in the mold. *Notice the warning not to ground the chassis.* The General Radio 200-B Variac permits control of the output from about 500 to 10,000 volts (no load). *High-voltage connectors and cable must be used for the output circuit.* A 0-200 microammeter in series with ten ½-watt resistors totaling 50 megohms is placed across the output terminals. This shows the voltage applied to the dielectric in the mold. A cheap multitester meter (0-1 ma) with a 1/16-ampere miniature fuse in the high-voltage leads shows the current that flows through the dielectric.

How to make electrets

The mold, with a 4-mm distance between electrodes, is placed on the Transite stand and inserted in the oven. Clip the high-potential leads inside the oven to the mold elements. The V5-M-T Variac is attached to the heating-element terminals, and the oven is heated to 100 degrees C.

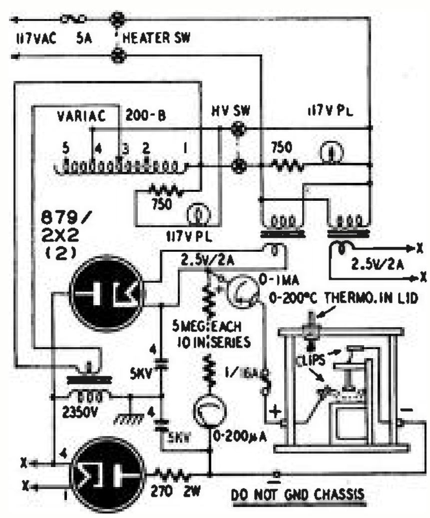


Fig. 3—Power supply furnishes high voltage.

Lift the lid off the oven. Pour the Carnauba wax-hydrogenated rosin mixture, previously heated to 110 degrees C in a beaker for one half hour to drive out moisture, into the mold through a small Pyrex funnel. Stop pouring when the molten mass is just deep enough to touch the upper electrode. Replace the oven lid and, when the thermometer again reads 100 degrees C, turn off the heating element.

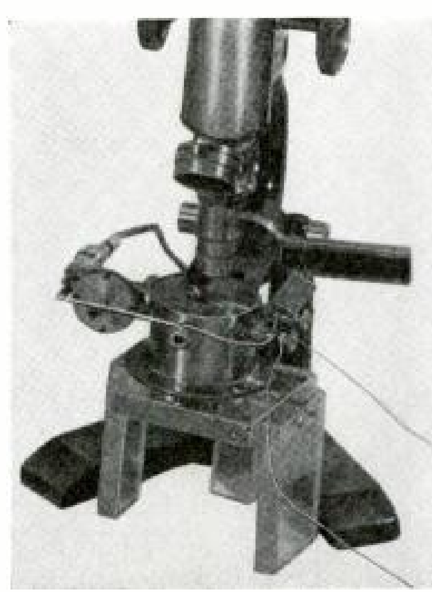
Disconnect the V5-M-T Variac from its terminals on the oven. Attach the high-voltage cables from the power supply to the colored high-voltage terminals on the oven. When the thermometer falls to 90 degrees C, turn up the 200-B Variac in the power supply until approximately 3,000 volts is applied to the mold. For a 4-mm distance between mold electrodes the field strength will be 7,500 volts per centimeter. Depending on the purity and the nature of the dielectric, the current through the molten mixture will be from about 400 to 1,000 microamperes. This current decreases as the dielectric solidifies, reading approximately zero at room temperature.

At room temperature turn the 200-B Varac to zero and turn off the power supply. Wait at least one minute before disconnecting the high-voltage leads at the power-supply terminals on the panel. Be careful to avoid shocks during this procedure; a shock from charged 4-μf condensers can be fatal.

Next, disconnect the mold from its leads inside the oven and take the stand and mold from the oven. Unscrew the top electrode and remove it from the stand. With the fingers lift the foil containing the electret from the lower electrode. Brush off loose flakes of dielectric. Fold the edges of the foil up over the electret until it is completely covered by foil. The foil acts as a keeper and has the same function as the keeper on a magnet. Completed electrets must be kept wrapped in foil and stored in a closed dessicator or fruit jar which contains about ¼ ounce of $CaCl_2$ or other dessicant.

Measuring the surface charge

The surface charges on electrets are measured with an electrometer—an instrument for measuring potential difference or indicating the presence of electricity. The gold-leaf electroscope is one type of electrometer. The Lindemann electrometer, used by this writer,



Electrometer is observed through microscope.

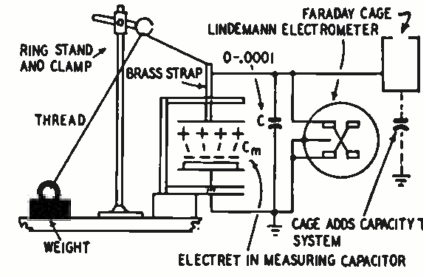


Fig. 4—Schematic of the electrometer setup.

is a metal box which contains four conducting plates. Opposite plates are connected internally to form two pairs of quadrants. A conducting needle, hanging from a fiber inside the box, completes this capacitor-type measuring instrument. Connect the needle to one pair of

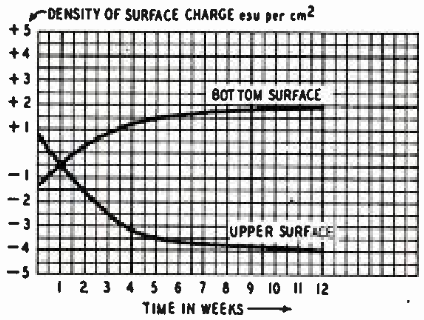


Fig. 5—A graph of surface-charge growth.

quadrants (see Fig. 4). A potential difference applied to the quadrants charges the electrometer (regarded as a capacitor) and deflects the electrometer needle. The deflection is proportional to the square of the applied potential difference. Thus batteries of known e.m.f. can be attached to the quadrants (electrometer terminals) to calibrate the electrometer measuring circuit. Graphs of electrometer deflection versus potential difference can be drawn for various values of C. C is a small mica capacitor that can be placed across the electrometer to increase the total capacitance of the measuring system. Consequently, when an electret is placed in the measuring capacitor Cm, the deflection corresponds to a known potential difference on a calibration curve. The deflection is

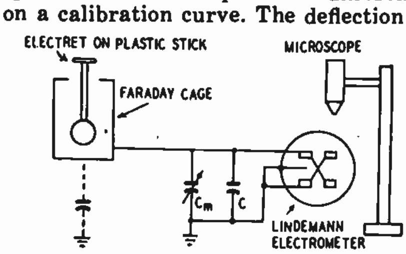


Fig. 6—Setup for finding electret polarity.

observed through a microscope and measured in terms of the units on an arbitrary scale in the microscope eyepiece. A photograph shows a closeup view of the electrometer and the microscope.

The measuring capacitor Cm (Fig. 4) is a modified N-10 Hammerlund capacitor. The capacitor plates are taken off the original insulator and cut down to a radius of 20 mm with a lathe. This makes the area of each plate the same as that of an electret. Then the plates are mounted on a plastic stand 2 inches high. Disregarding the thicknesses of the base and top arm of the plastic mount, the maximum distance between plates will be 1⅛ inches.

A thin brass strap 3 inches long by ⅜ inch wide is soldered to the top plate of Cm. The strap slides up and down through a slit in the top arm of the mount. A silk thread is attached to the free end of the strap. The other end of the thread is tied to a weight (a heavy nut). Looping the thread over a laboratory ring stand and moving the weight by hand permits adjustment of the distance between plates of Cm.

A Faraday cage is connected to the high side of the electrometer measuring circuit. The dotted capacitor in the drawing shows that the cage adds capacitance to the circuit. The Faraday cage is a metal cookie can with the lacquer removed. Its use will be apparent in a moment.

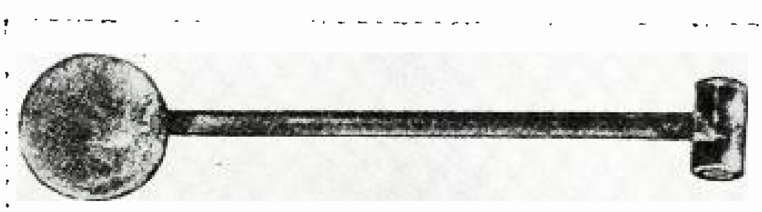
The total capacitance of the measuring system, with maximum distance between plates of Cm, is measured by the substitution method. For a 50-μμf value of C the total capacitance was 61 μμf.

The electret's charge

The observed growth of charge on electret surfaces follows the exponen-

Fig. 7—Lifting electret from Faraday cage.

tial curve predicted by E. P. Adams of Princeton University. The time required for the charges to reach maximum values is from 2 to 4 months. The growth of charge for one of the author's electrets is shown in Fig. 5. This graph



The electret is mounted on a plastic handle so that it need not be touched with the hands.

shows a reversal in the sign of the charge on each surface as time passes. Also, this graph shows that the sign of the net charge of Carnauba wax electrets is negative.

To find the *sign* of the net charge on an electret the Faraday cage (see Fig. 6 and the cover picture) is used. Insert the electret in the Faraday cage, first short-circuiting the measuring circuit with a small piece of wire in an insulated handle (pigtail in cover photo). Then remove the short-circuit and lift the electret from the cage as shown in Fig. 7. The work done in lifting the electret from the cage induces charges on the sides of the cage, charges the circuit capacitance, and causes an electrometer deflection. The sign of the induced charges is opposite that of the charges on the electret. Then bring a charged rubber or glass rod near the Faraday cage. When the electrometer shows a decreased deflection, it indicates the sign of the net electret charge is the same as that on the charged rod. A charged rubber rod (negative) always causes a decreased electrometer deflection, showing that the net electret charge is negative. This is based on the principle that unlike charges attract.

To find the actual *magnitude* of charge on an electret *surface* the measuring capacitor Cm (Fig. 4) is used. Place an electret on the bottom plate of Cm. With the measuring system short-circuited, lower the top plate of Cm until it touches the electret surface. Then remove the short circuit. Raise the top plate of Cm to the top of the plastic mount. Raising Cm causes work to be done and induces a charge on the top plate of Cm. The sign at the induced charge is opposite to that on the electret surface. The work done charges the measuring system capacitance and deflects the electrometer needle. The deflection is noted, and the corresponding potential difference read from a calibration curve.

To obtain the *total* charge on the electret surface the relation $Q=CV$ is used. The total capacitance C is known. Since 0.9 × capacitance, in microfarads equals centimeters of capacitance, and practical volts (p.d.) divided by 300 equals statvolts, the total charge Q on the surface is obtained in statcoulombs. The *density of surface charge* is Q/A_e, which is statcoulombs per square centimeter. A_e is the electret area. Reversing the electret in Cm, and repeating the procedure gives the density of surface charge for the other electret surface.

For these surface-charge measurements the electrets were mounted as shown in the photographs on plastic handles, to prevent the observer from becoming charged and to make it unnecessary to touch the electret at any time.

Eguchi and Gemant found the relative density of surface charge, under ideal laboratory conditions, to be approximately 6 statcoulombs per square centimeter. To find the magnitude of surface charge for practical purposes this writer used the above method and depending on the type of electret, found that the density of surface charge varied from 0.25 to 4.00 statcoulombs per square centimeter.