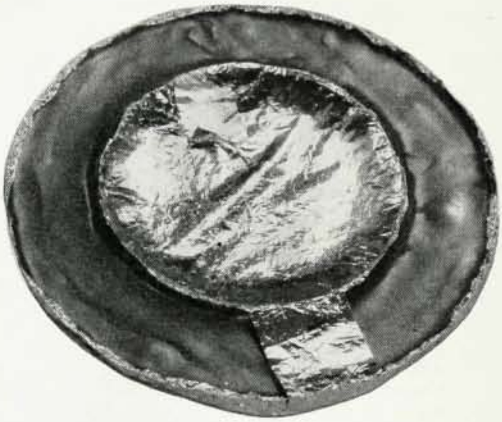
ELECTRETS



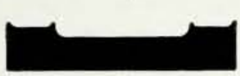
The electret,
an electrical counterpart
to a permanent magnet,
theoretically isn't supposed to exist.
Yet the author made one
which is still "alive"
after twelve years.
He discusses how electrets may be
used and some of the problems
in understanding them.

by Andrew Gemant

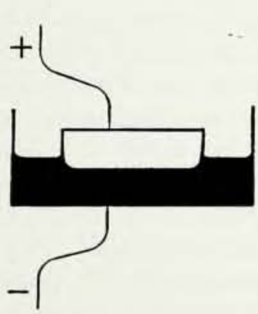
Electrets are the electrical equivalent of permanent magnets—they carry a permanent positive charge at one surface, and a permanent negative charge at the opposite surface. The most remarkable thing about them is that, theoretically, they cannot exist! Yet they do exist, posing a problem that has not yet been solved.

The reason why an electret, in contrast to a permanent magnet, is theoretically impossible can be explained in the following manner. In all matter there are true electric charges present, basically protons and electrons, and in some cases more complex charged molecules, the ions. A polarized material produces an electric field that causes these electric charges to migrate until they neutralize the field produced by the polarization. In contrast to this, true magnetic charges do not exist (according to our present-day knowledge), and a magnetic polarization, once established, might persist indefinitely.

Heaviside used, in his theories, the concept of a permanently polarized material, an electric dipole, and called such a fictitious object an electret. Rather unexpectedly, Eguchi announced the making of an electret in 1925. The reaction of physicists to his publication was lukewarm; they considered the whole subject a freak. Only very few publications on the subject appeared in subsequent years, and even now the literature in that field is scanty. It appears, however, that interest in electrets is definitely growing in the last few years.



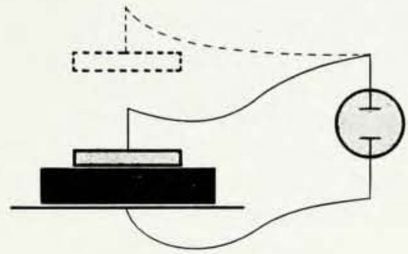
The wax electret . . .



. . . in a metal container acting as one electrode.

Making Electrets

The basic material most commonly used to make electrets is carnauba wax often mixed with rosin. Carnauba wax is an extremely hard vegetable wax, melting at about 85 degrees Centigrade. It can be polarized when molten. To make an electret the molten wax is put in a moderately strong direct-current field, perhaps five thousand volts per centimeter. Next, the wax is solidified while still in the



Electret field can be measured with an electrometer.

field. In this manner, the polarized particles, whatever they may be, are fixed. When the wax has attained room temperature it may be removed from the field. It is now an electret. Very little power is required from the generator, since the electrical conductivity of the wax is low.

How do we know that the electret is "live"? It would be naive to connect the two surfaces to a galvanometer and attempt to measure currents, however small. It must be understood plainly that an electret is no battery. To be sure, it contains a certain amount of stored electrostatic energy, but the amount is insignificant; it is negligible compared with the energy stored in a battery of equal volume. An electret is merely a device to produce an electrostatic field, and this field can be measured (to prove that it is polarized) by connecting the lower surface of the electret to one terminal of an electrometer and lowering an insulated metal plate,

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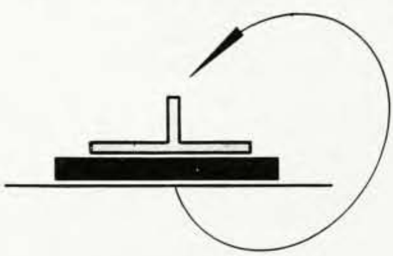
connected to the other terminal of the electrometer, upon the bare top surface. By induction, a charge equal in sign and magnitude to that of the top electret surface will collect on the electrometer where it can be measured.

There is another way, more impressive perhaps, but merely qualitative, with which one can show that an electret carries free electric charges. It is possible to draw a little spark one to three millimeters long from an electret by grounding one side of the electret on a metal base to which a needle is connected with wire. An insulated metal plate, attached to a metal rod, is then placed on the bare top surface. If the top surface carries a positive charge, a corresponding positive charge will collect at the far end of the metal rod. If the needle is brought close to this rod, a little spark will discharge the positive electricity of the rod. The plate



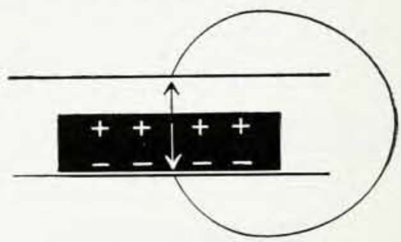
Drawing a spark from an electret.

is then removed, momentarily grounded and placed again on top of the electret, ready for the next spark. This experiment may be carried out many times in succession without reducing the charge of the electret.

This seems rather puzzling since a spark converts a certain amount of electrical energy into heat. Where does this energy come from if not from the electret itself? It comes from the mechanical work we ourselves do in removing the top metal from the electret surface in order to make ready for the next spark. This mechanical work, done against the electric attraction forces, restores the potential energy of the free charge which is then ready to deliver the next spark. This clearly shows that the electret is no energy source in the sense of a battery.

What They Do

One of the most startling features of an electret is the sign of its charge. Let us assume that the top electrode used in making an electret is connected to the positive terminal of a generator. The top surface of the completed electret will then carry a negative charge, a sign opposite to that of the polarizing electrode. This charge is called a heterocharge. By measuring this charge on successive days it is found that its magnitude decreases, becomes zero after about one week, and reverses its sign in the following days. This reversed sign is always the same as that of the polarizing electrode and is called homocharge. It attains its final value in about another week and if the electret is properly stored, is remarkably permanent. The author made an electret twelve years ago and it is still alive.



Field times gap length is equal and opposite to field times length of electret.

How big is the charge? Or, to put it another way, what is the potential difference of an electret? If an electret is placed on a metal base and faces another metal plate wired to the base, then the electric circuit consists of the electret and an air gap in series, the field in the air gap opposing the field in the electret. The potential of the electret (field times electret length) is equal and opposite in sign to the potential drop across the gap (field times gap length). This is the same relation as is known from permanent magnets, and, although not yet proved experimentally, it is probably valid also for electrets. Basically such a relation follows from the elementary laws of electrostatics.

If the gap is small, the electret produces a maximum field at its surface (as much as twenty-five thousand volts per centimeter for a half millimeter gap). If the gap is larger, the free charge and the field in the gap are reduced. This reduction is pronounced and can be measured. It follows from these considerations that, for a given gap length, the field should increase with increasing electret thickness. This is an interesting conclusion which, however, has not yet been checked experimentally. Because of experimental difficulties, making a very thick electret is certainly not an easy task. One might perhaps try to produce a thick electret by piling up a number of thin disks. If this were possible, the usable gap potential might be increased beyond its present value.

A short gap is advantageous not only to obtain a high field intensity, but also for good permanence. In this respect, the similarity to permanent magnets is close. Electrets must be kept "short-circuited" when stored. This is because the diselectrifying field inside the electret is a minimum when the gap length is zero, and accordingly the depolarization process will be slowest. In the photograph of a disk electret, the central active part is covered with tin foil and electrically connected to the base.

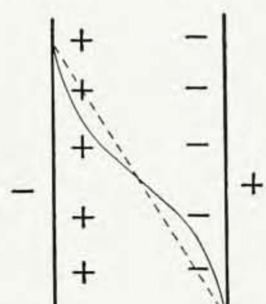
In this connection another precautionary measure in the use of electrets should be mentioned. It is important to keep an electret in a dry atmosphere. When an electret with a bare surface is brought into a space with a rather high humidity its field diminishes because a thin layer of moisture absorbed at the surface acts as an electric shield. When the electret is brought into a dry chamber again, the moisture evaporates and its original field is restored. This is a significant difference in comparison with magnets and is certainly a disadvantage as far as practical uses of electrets are concerned. There are no data yet regarding the upper limit of the range of relative humidity at which electrets can be used.

With increasing temperature a depolarization takes place. Near room temperature this process is entirely reversible, inasmuch as lowering the temperature restores the original charge. When the temperature is raised to a degree sufficient to soften the electret, the charge gradually disappears in an irreversible fashion. Near the melting point the charge is completely destroyed.

Heterocharge

The explanation of the heterocharge is relatively simple. Carnauba wax is a very good insulator at room temperature, but becomes a rather poor one at higher temperatures. If a direct-current source is applied to the molten wax, the ions migrate to the electrode of opposite sign, where they accumulate. These ions are fixed when the wax is cooled and form a space charge whose sign agrees with that of the heterocharge.

There are several proofs in favor of this explanation. If ions accumulate near the electrodes, the corresponding charge must flow away from the electrode into the outer circuit producing a current called charging current. Such charging currents have often been measured on electret-forming waxes.



The solid line shows potential drop across an electret is like that of space charge.

A more direct proof of the existence of ionic layers in the neighborhood of the electrodes is supplied by observing the potential distribution. The potential drop across a dielectric, to which a voltage is applied, varies uniformly in the absence of a space charge. If ions are accumulated and form corresponding space charges, the potential drop is greater near the electrodes and correspondingly smaller in the center portion of the dielectric. By using probes inserted in the wax at various distances from the electrodes, it is actually possible to measure the variation of the potential between the electrodes. The results obtained are typical for space charges as postulated.

Because of the finite conductivity of the electret even at room temperature, one can expect accumulated charges to be neutralized after a certain time. A measure of the rate of this process is the so-called time constant. This may be estimated to be of the order of magnitude of a day which means that an accumulated space charge is neutralized completely within a few days. This conclusion is in good agreement with the observed disappearance of the heterocharge in the course of a week.

So far it seems that the mechanism of electrets presents no particular puzzles.

Homocharge

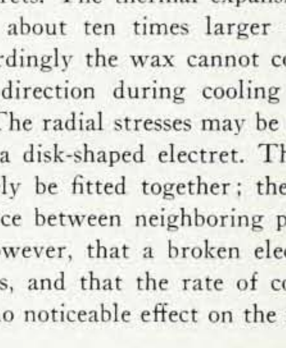
The situation is entirely different with regard to the homocharge, for which no proven explanation exists. Both its sign and its permanence are remarkable, to say the least. It appears that the effect is clearly one of volume and not of surface, a circumstance that eliminates explanations based on a surface effect. If the surface of an electret is gradually shaved off, the electric field reappears after each operation, indicating that the polarizing process must extend through the bulk of the material.

What follow are more or less fragmentary ideas, supported by some experimental evidence. It seems that the mechanism of the homocharge is independent of that of the heterocharge. The two processes take place independently of each other, each producing its own charge. This follows from the observation that carnauba wax alone produces mainly a permanent homocharge, while rosin alone produces merely a temporary heterocharge. A mixture of the two results in the reversal of sign as described earlier. Thus the two independent processes are additive in nature.

There is an indication that the homocharge might be caused by an orientation in the high direct-current field of dipolar molecules, which subsequently attract each other and form minute crystals embedded in a hard medium. These crystallites may be likened to the "domains" that play an essential role in ferromagnetism. If this assumption is correct, the presence of a crystal orientation ought to be detectable by x-ray diagrams. Some investigators have verified this conclusion, but definite proof is still missing.

If the importance of oriented crystallites should be definitely established, one might go one step further and explain the homocharge by assuming that the crystallites are piezoelectric (undergoing mechanical strain when under electrical stress and vice versa) and that, because of an internal stress in the electret, they produce a polarization in the right direction. Some investigators, but not all, have observed piezoelectricity in wax-type substances. The phenomenon appears to be similar to the change of magnetization of a permanent magnet under the influence of applied or internal tension.

There can be no doubt that internal stresses exist in electrets. The thermal expansion coefficient of waxes is about ten times larger than that of metals; accordingly the wax cannot contract freely in a radial direction during cooling after it has been made. The radial stresses may be demonstrated by breaking a disk-shaped electret. The pieces cannot completely be fitted together; there remains a narrow crevice between neighboring parts. It must be added, however, that a broken electret still exhibits charges, and that the rate of cooling during making has no noticeable effect on the final product.



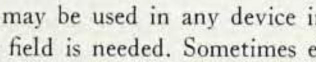
Once cracked, the pieces of an electret do not fit back together again.

As stated above, this phase of the research is by no means settled, but the writer is inclined to think that crystal orientation does play a role in the formation of the homocharge.

Use

Electrets may be used in any device in which an electrostatic field is needed. Sometimes electrets are called electric magnets. This name is misleading inasmuch as some might conclude that an electret could be substituted for a magnet. Consequently, the name electric magnet is best avoided.

One device in which electrets can be used is an electrometer with an auxiliary electric field, usually supplied by a battery. If electrets are substi-



Electret Microphone.

tuted for batteries, the weight is markedly reduced and the life extended, advantages that may be of value in recording balloon instruments, for instance. A second possibility is the use of electrets in microphones. In such a device the electret is completely enclosed in a rather small space so that there is no danger of a deleterious effect from moisture. The free surface of the electret is covered by a metal mesh and at a short distance there is a thin metallic membrane. When sound waves hit the membrane, it vibrates. The charges induced on the membrane produce an alternating voltage at the output terminals, which is a true reproduction of the sound wave. While we have published records of electrometers built with the aid of electrets, electret microphones and their operational characteristics have not yet been mentioned in the technical literature.

A third possibility is the use of electrets in discharge tubes in which an electrostatic field is needed as a control. Some people might doubt the usefulness of an electret in the presence of gaseous ions which might neutralize the free charge. Perhaps a high vacuum tube in which only electrons, but no ions, are present, in conjunction with electrets that have only their negative surfaces bared, might be a workable arrangement. The negative electret surfaces would repel the electrons and accordingly there would be no danger of neutralization. Such devices have not been tried yet on an experimental scale.

Wax electrets suffer from various disadvantages that become particularly noticeable when practical uses are considered. They are not easily machined and are altogether too brittle. They are sensitive to high humidity. They have a relatively low melting point. All these factors are drawbacks from an engineering viewpoint. It appears, therefore, that before electrets can be seriously considered for practical use their mechanical properties will have to be improved. The making of electrets from plastics of high softening point, from glass, or from ceramics appears to be a promising avenue of approach. Barium titanate ceramics have very high dielectric constants (above 1000); they are composed of domains and have a Curie temperature above which these properties disappear. Since these characteristics are analogous to the magnetic properties of iron, they might be a good choice for ceramic electrets.

In some articles mention has been made of attempts to make electrets from plastics, but these rumors have not yet been confirmed by publications in technical journals.

Progress on electrets in the near future may be expected to come from three different approaches. First, there is the basic physical mechanism of the homocharge, as yet unsettled. Second, electrets will be made of plastic and ceramic materials, and these will have better mechanical properties than have wax electrets. Third, engineering applications will be found which we probably don't even imagine today.