APPARATUS AND DEMONSTRATION NOTES

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This department welcomes brief communications reporting new demonstrations, laboratory equipment, techniques, or materials of interest to teachers of physics. Notes on new applications of older apparatus, measurements supplementing data supplied by manufacturers, information which, while not new, is not generally known, procurement information, and news about apparatus under development may be suitable for publication in this section. Neither the *American Journal of Physics* nor the Editors assume responsibility for the correctness of the information presented. Submit materials to Daryl W. Preston, *Editor.*

Showing dispersion for the dielectric permittivity of ice

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(Received 21 November 1997; accepted 8 May 1998)

The propagation speed of electromagnetic radiation rough a medium is frequency dependent and so, quantities lated to the propagation speed exhibit dispersion. It is usual examine dispersion for a refractive index over the range of tical frequencies. But it is also instructive to consider disrsion for the dielectric permittivity at kilohertz frequenes.

Maxwell's equations give the electromagnetic wave speed rough an isotropic dielectric[1] as

$$v=1/(\epsilon\mu)^{1/2}, \tag{1}$$

here ϵ is the permittivity and μ is the permeability. Since e absolute index of refraction is defined by

$$n\equiv c/v, \tag{2}$$

here c is the speed of light in vacuum, there follows the axwell relation for weakly magnetic substances (whose lative permeability is essentially one):

$$n\approx(\epsilon/\epsilon_0)^{1/2}, \tag{3}$$

here ϵ_0 is the vacuum permittivity. Note that the Maxwell lation, Eq. (3), must be applied at the same frequency for th the index of refraction and the permittivity.[2] The wellown values $n_{\text{water}}\approx 1.33$ and $(\epsilon_{\text{water}}/\epsilon_0)^{1/2}\approx 9$ are misatched in this regard since the refractive index is that at tical frequencies ($\sim 5\times 10^{15}$ Hz) while the relative perittivity is that for a constant field or for very low frequenes (less than 10^4 Hz).

In this note we outline how to examine dispersion for the rmittivity of ice over the frequency range 10–200 kHz of e electromagnetic field.[3]

The lab capacitance of a dielectric-filled, parallel-plate cacitor may be written as

$$C=(\epsilon/\epsilon_0)C'+C_0, \tag{4}$$

here C' is the ideal, empty-condenser capacitance and C_0 the general background capacitance. With just air between plates,

$$C_{\text{air}}\approx C'+C_0. \tag{5}$$

With paraffin between the plates,

$$C_{\text{par}}=2.26C'+C_0.$$

Measuring C_{air} and C_{par} fixes C' and C_0. Thus, measurements of C_{ice}, the capacitance with ice between the plates, can be used in Eq. (4) to find the dielectric permittivity $\epsilon(\nu)$ for various frequencies ν of the electromagnetic field between the ice-filled plates.

The experimental circuit is shown in Fig. 1. A low voltage ($\sim$10 V), variable-frequency electromotive force from an audio generator is connected to a simple transformer ($\sim\times 10$) consisting of two coaxial solenoids (the inner coil has tens of

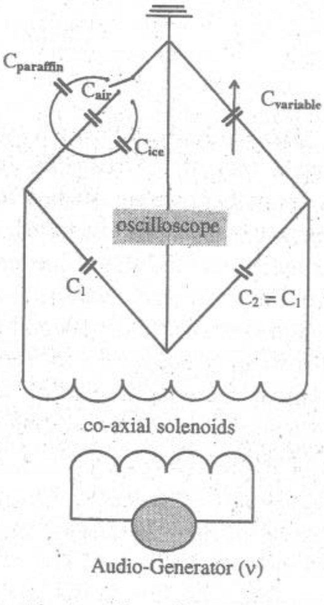

Fig. 1. The experimental setup. The audio-generator voltage is transformed upwards ($\sim\times 10$) by coaxial solenoids. The bridge consists of identical capacitances $C_1=C_2$, a calibrated variable capacitor C_{variable}, an oscilloscope, and the capacitances to be measured.

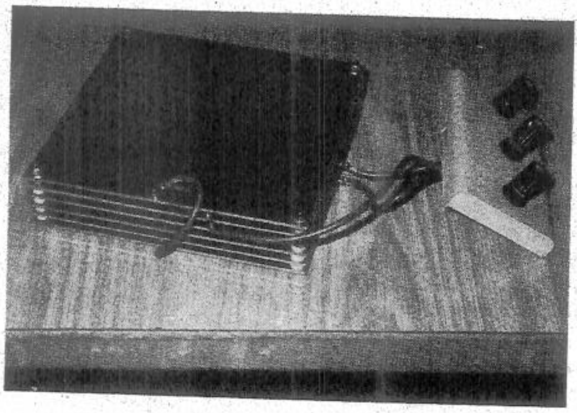

Fig. 2. A tier of three capacitors.

loops and the outer has several hundred loops) with the inner coil filled with bundles of iron wires. The capacitance measurements are done by a null method using a bridge consisting of two known equal capacitors C_1, C_2 (in the 10^3 pF range), a calibrated variable capacitor C_{variable}, an oscilloscope, and the sample capacitor. The variable capacitor is adjusted until there is a zero reading on the oscilloscope.

It is convenient to use a tier of three capacitors, shown in Fig. 2, made from six identical plates ($14\ \text{cm}\times 14\ \text{cm}$) set parallel to each other with a 5-mm spacing. The top capacitor is wrapped with tape and filled with liquid paraffin which solidifies as it cools. The middle capacitor is left empty. The bottom capacitor is placed into a shallow container of water which is then frozen. The excess ice is easily removed.

Figure 3 summarizes the experimental results for the relative permittivity of ice, $\epsilon(\nu)/\epsilon_0$, as a function of the field frequency, ν. The ice permittivity falls off rapidly at frequencies $>10^4$ Hz, unlike the permittivity of room-temperature water whose fall is gradual up to $\sim 10^7$ Hz.

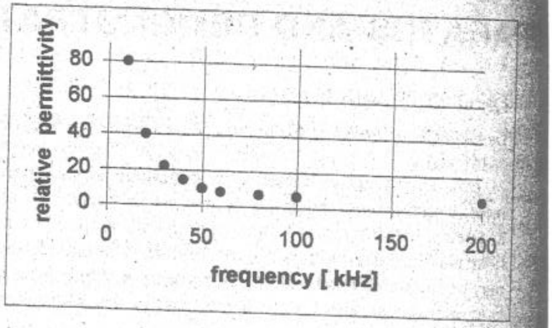

Fig. 3. The relative dielectric permittivity of ice $\epsilon(\nu)/\epsilon_0$ for various of the frequency ν of the electromagnetic field.

N. Malov has pointed out an alternative method for ing dielectric permittivity. Two identical parallel-plate pacitors, C_A filled with ice and C_B left empty, are connec in series to a voltage oscillating with frequency ν. An os loscope or cathode voltmeter is used to measure the volt across each capacitor:

$$V_A \approx I/(2\pi\nu C_A), \quad V_B \approx I/(2\pi\nu C_B),$$

where I is an effective current. But

$$C_A/\epsilon_{\text{ice}} \approx C_B/\epsilon_0.$$

Therefore,

$$(\epsilon_{\text{ice}}/\epsilon_0) = (V_B/V_A).$$

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[1] D. Halliday, R. Resnick, and K. S. Krane, *Physics* (Wiley, New 1992), 4th ed., Vol. 2, pp. 877–880; W. H. Hayt, Jr., *Engineering tromagnetics* (McGraw–Hill, New York, 1989), 5th ed., p. 341.

[2] These quantities are also temperature dependent.

[3] See also: A. Gingle and T. M. Knasel, ''Undergraduate laboratory tigation of the dielectric constant of ice,'' Am J. Phys. **43** (2), 161 (1975). R. P. Auty and R. H. Cole, ''Dielectric properties of ice and D_2O,'' J. Chem. Phys. **20**, 1309–1314 (1952).

OPENNESS TO NEW IDEAS

The late Richard Feynman stated in an interview on PBS some years ago that the common view that it took thirty years for relativity and quantum mechanics to be accepted by the physics community is wrong. Rather, he suggested that the real reason is that the half-life for physicists is thirty years—or in lay terms, it took thirty years for all the old physicists to die. In my own experience, it is almost never one's contemporaries who recognize the value of one's ideas, especially the more controversial ones. It is almost always the most senior members of the community, and the students. Both my observation and that of Feynman would seem to suggest that we as scientists are not very open to new ideas once we have completed our education, at least until we are near the end of our careers. Perhaps we have such an investment in assembling the structure of our understanding that we simply cannot be open to ideas that appear to challenge its foundations.

William K. George, in *Editing the Refereed Scientific Journal*, edited by Robert A. Weeks and Donald L. Kinser (IEEE Press, New York, 1994), p. 229.