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On the Measurement of the Dielectric Constants at Ultra-high Frequencies[1]

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Introduction

One of the methods of measuring dielectric constants of solids and liquids at low and radio-frequencies is that of measuring the capacitances of a condenser with and without the medium of unknown dielectrics between its plates. At sufficiently high frequencies, the relative change in magnitudes of inductive and capacitive reactances makes the experimental technique and the mathematical calculations complicated.

R. King(1) devised a parallel wire method for measuring the dielectric constants at ultra-high frequencies. In his method a relatively small sample in the form of a thin slab was used, which was moved along the parallel wires and the value of the maximum shift of the short bar position was used for the calculation. Okazaki, Takayama and Yamamoto(2) set always the sample at the position of $\lambda/4$ from the short plate and calculated from the shift of this position. For small values of the dielectric constants these two cases give almost the same results.

We have also measured several substances by these methods. In the case of a rochelle salt the variation of dielectric constant as the function of the temperature was observed. The results with the parallel wire method agree comparatively well with those in other methods and frequencies(3)(4).

Experimental procedure

1. *Apparatus.* The experimental arrangement is schematically shown in Fig. 1. The oscillator was a usual feedback type of triode, the grid and the plate of which were attached to the parallel wires. The wave length was varied by sliding the short bar of this wires,

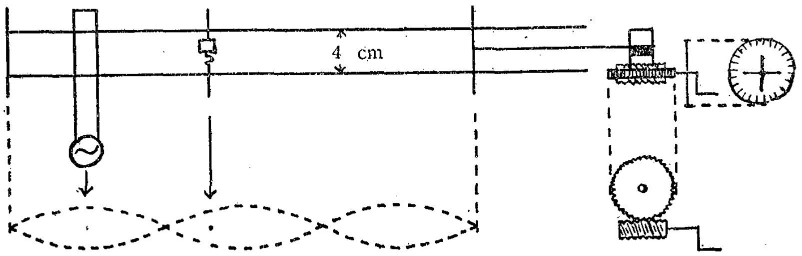

Fig. 1.

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[1] Contribution from Department of Physics, Faculty of Science, Ochanomizu University, No. 14.

and the obtained region ranged from 80 to 400 cm in wave length. This oscillator was placed under the wave meter at 15 cm distant and about the position of the voltage loop. The wave meter consisted of parallel wires of about 2.5 m long and 4 cm separation, and two end plates of 40 cm in diameter, one of which could be smoothly moved along these wires with the aid of a worm gear.

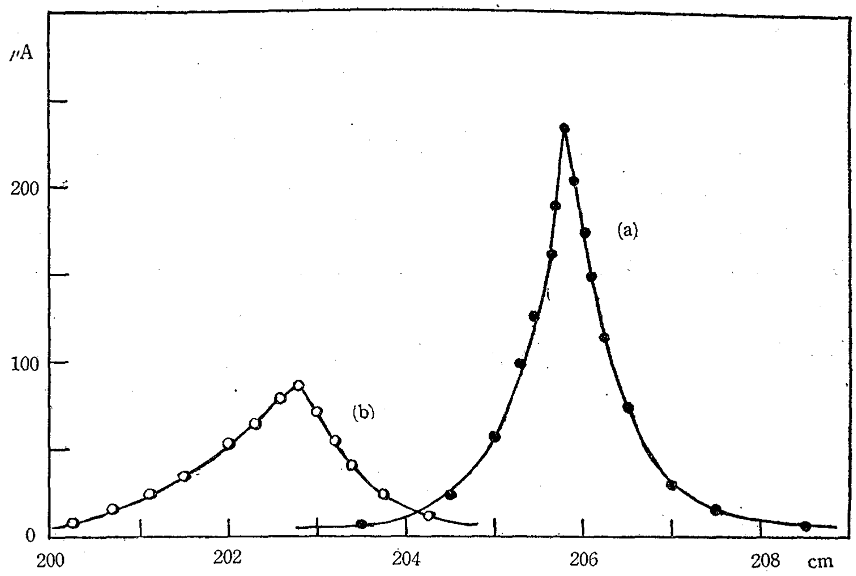

Fig. 2.

Fig. 2.
Resonance curves
(a) ebonite
(b) Japanese cypress

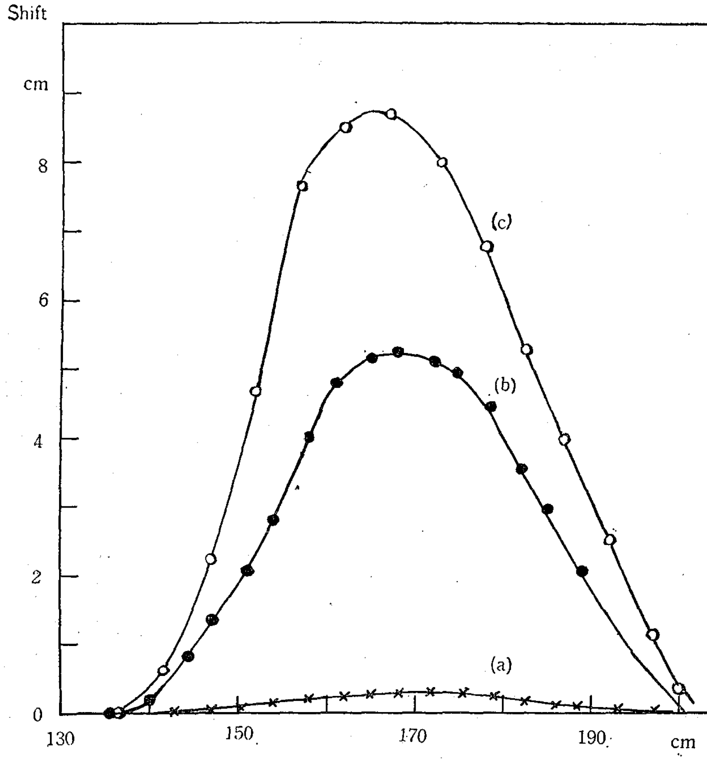

Fig. 3.

Fig. 3.
The shift versus position of the sample
(a) ebonite
(b) rochelle salt
(c) water

Fig. 2 shows the current in crystal rectifier against the short plate position. The resonant position was obtained from the maximum current position which could be read in 1/10 mm accuracy.

2. *Measurement of the dielectric constants.* When the sample was inserted between the parallel wires, the position of the short plate which indicated the maximum current shifted. The shift curve against the position of the sample was plotted. The examples for several substances are illustrated in Fig. 3. From these curves we can see that the positions of the maximum shift are almost at $\lambda/4$ for the substances which have the small dielectric constants. In order to obtain the temperature variation of the dielectric constant of rochelle salt the sample was set in a box of paper which had two electric heaters at both sides symmetrically and by controlling the heater current the temperature was varied. The shift due to this box was corrected by the following equation,

$$\tan\tfrac{1}{2}\beta(s'-s_2)_f-\tan\tfrac{1}{2}\beta(s'-s_2)_e+\tan\tfrac{1}{2}\beta s_1=n\tan\tfrac{1}{2}\beta n s_1\ ,$$

where the subscripts, f and e, refer to the maximum values of the quantity $(s'-s_2)$ with the cell full and empty respectively, β is propagation constant, $(s'-s_2)$ is the shift values plus s_1 and s_1 is the thickness of the sample. For thin walls and small s_1 the equation can be simplified. For the sample of liquid an ebonite cell was used and cemented with paraffin around the parallel wires which piereced through the cell. For a solid dielectric substance the necessary equation was reduced to the following,

$$\tan\tfrac{1}{2}\beta(s'-s_2)=n\tan\tfrac{1}{2}\beta n s_1\ .$$

Using this simple technique the dielectric constants of various substances were measured.

3. *Dimensions and thickness of the samples.* The theory assumes that the sample is flat and infinite extension and is piereced perpendicularly by two parallel wires. R. King calculated the fraction of the total field contained in the sample and evaluated the ratio of the displacement current flowing in the sample to the total current leaving from one wire. This ratio is at the dimension of the sample of 15×30 cm^2 in separation of wires of 2 cm, 0.9995 for water ($\varepsilon=80$) and 0.9554 for air ($\varepsilon=1$). The sample of necessary dimension was not always obtained. Therefore, various sizes of ebonite plates have been examined, and the ratio of the maximum shift of the small sample to the large one to which the above theory can be applied was tested. This percentage fraction was used in calculation of unknown small dielectric constants. For large values the percentage fraction was checked with water. The sample which is so wide as the parallel wire separation indicated very small fraction of the shift. But the shift of the sample which is larger than the separation of the wires became abruptly larger. From this phenomenon it was

known that the effect which came from surrounding the wire with sample was very important.

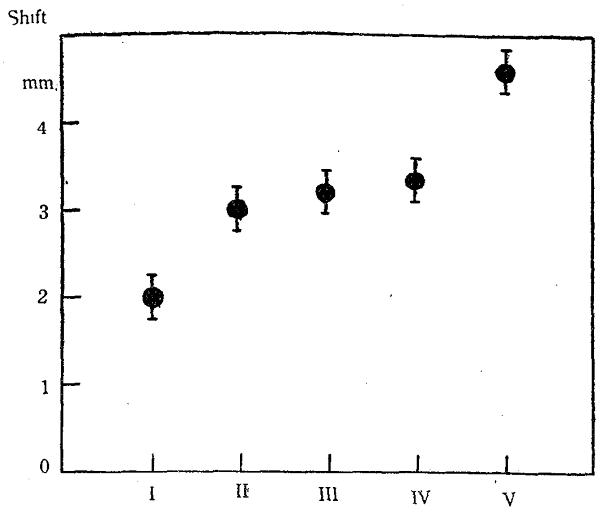

Fig. 4. Shifts for various sizes of ebonitc plates.
I 4×10 II 7.5×6 III 6×13
IV 8×9 V 10×15 cm²

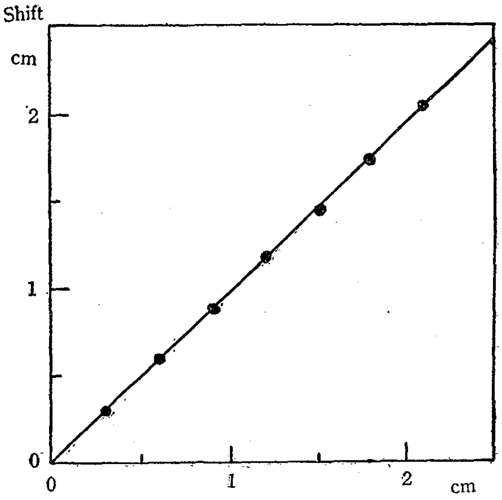

Fig. 5.

The necessary thickness of the sample must be at least such that the shift produced by this sample is measured in experimentally allowable accuracy. The surface of the sample also must be flat, because the variation of the thickness at any portion makes the calculation complex. Fig. 5 shows one example of the shift against the thickness of ebonite plate of 3 mm. In the case of a rochelle salt, the crystal dimension was not so large that the ebonite plate was cut as the same shape as the rochelle salt and in calculation the result was corrected with this ebonite.

Results and discussion

Table shows the results in this measurement. In spite of that the percentage corrections were added to the observed shifts the values obtained agreed thoroughly with other measurements.

It has been known that the rochelle salt have an enormous large dielectric constant in direction of *a* axis, but the values in the directions of the *b* and *c* axes are as large as the values of usual crystals. At low frequencies these values and the variation against temperature were studied well. In the present experiment the values of the direction of *a* and *b* axes were obtained and the variation of the shift for temperature was tested in the direction of *b* axis. As shown in Fig. 6 the temperature coefficient is positive as usual crystals and agrees well with the values at other low frequency measurements⁽⁵⁾. At about 25°C the points deflected to larger value of the shift which was thought as the effect of *a* axis.

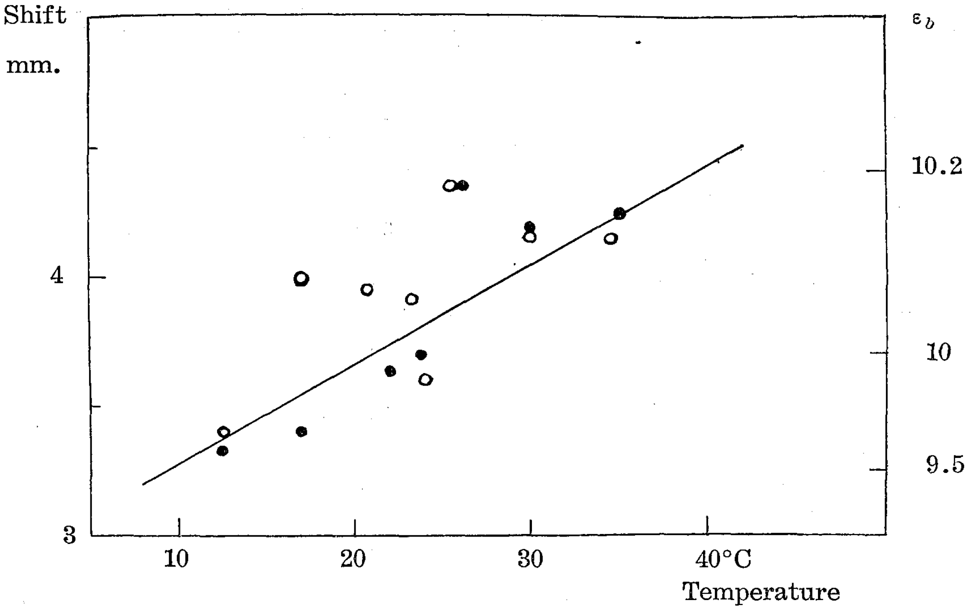

Fig. 6.

Table 1.

Name	Dielectric Constant	Name	Dielectric Constant
Japanese cypress	2.6	Rock salt	7.1
Ceder	2.1	Marble	8.2
Pulp	1.7	Rochelle salt *b*	9.6 (12°C)
Beeswax	1.5	Rochelle salt *a*	106 (12°C)
Paraffin	1.7	Water	83.8 (15°C)
Ebonite	3.0	Alcohol	25.8
Bakerite	5.3	Glycerin	44
Benzol	2.5	Pump oil	2.7

Finally we want to express our sincere thanks to Mr. K. Kudo at Institute for Optical Research, Tokyo University of Education for making crystal of rock salt and to Miss Uchida and Miss Minematsu for their assistance for this experiment.

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