

V. L. Gurevich. *Dielectric relaxation and the thermopolarization effect in crystals*. The first part of this paper gives the theory of high-frequency dielectric losses in crystals. These losses will occur in any dielectric placed in an alternating uniform electric field. The result is that the field energy is dissipated as heat.

The problem of dielectric losses was first formulated by Debye. He considered losses in a polar liquid whose molecules had constant dipole moments.

This paper discusses the theory of high-frequency dielectric losses in crystalline dielectrics such as, for example, NaCl and ZnO, which do not contain freely rotating dipoles and the only possible motion is the vibration of the crystal lattice (phonons) whose interaction with the alternating field governs the above losses. An analysis is given of the basic physical processes underlying the phonon contribution to the losses. This contribution is relatively large and can be detected experimentally only at sufficiently high temperatures  $T$  and for field frequencies  $\omega$  for which it is much greater than the nonphonon contribution due to lattice defects (see, for example, Ref. 2 for further details relating to the latter).

The phonon contribution is different in crystals with and without a center of symmetry, respectively. In the latter case, it can be represented by the sum of two different terms.<sup>3-5</sup> The first of these terms has a frequency (but not temperature) dependence resembling the Debye shape: at low frequencies, the tangent of the loss angle,  $\text{tg } \delta$ , increases in proportion to  $\omega$ , reaching a maximum when the frequency is of the order of the re-

ciprocal of the phonon relaxation time  $\tau$ . It then falls as  $1/\omega$ . The second term increases monotonically with both frequency and temperature. The nature of this increase is determined by the crystal class (sometimes by the space symmetry group of the crystal). Thus,  $\text{tg } \delta$  is a nonmonotonic function of  $\omega$  for crystals that are not centrally symmetric (Figs. 1 and 2).

In centrally symmetric crystals,  $\text{tg } \delta$  contains only the contribution due to the second term<sup>6,7</sup> and the character of the increase is again determined by crystal symmetry<sup>3-5</sup>. In most cases, the losses in crystals that are

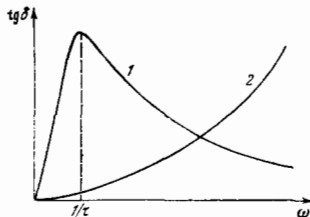


FIG. 1. Schematic illustration of the contributions to  $\text{tg } \delta$  as a function of the frequency  $\omega$  of the field: 1—quasi-Debye contribution to the losses, which is present only in crystals without a center of symmetry: it is proportional to  $\omega$  for  $\omega\tau \ll 1$ , reaches a maximum at  $\omega \approx 1/\tau$  and decreases as  $1/\omega$  for  $\omega\tau \gg 1$ ; 2—non-Debye contribution which is present in crystals of any symmetry: it increases monotonically with frequency: for  $\omega\tau \ll 1$  the increase is linear and for  $\omega\tau \approx 1$  the increase is proportional to  $\omega^n$  where the exponent  $n$  depends on the crystal symmetry. It is assumed that the frequency  $\omega$  is much lower than the limiting phonon frequencies.

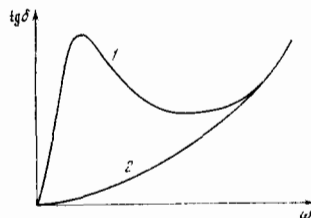


FIG. 2. Comparison of the general behavior of the frequency dependence of  $\text{tg } \delta$  in crystals with (2) and without (1) a center of symmetry at temperatures greater than or of the order of the Debye temperature. It is clear that where the frequencies are not too high the losses in crystals that are not centrally symmetric are much higher than those in centrally symmetric crystals.

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The second part of this paper discusses another (but theoretically similar) kinetic phenomenon in dielectrics, namely, the thermopolarization effect. In this effect, dielectric polarization is produced by a temperature gradient. Here again the theory of the effect is different for noncentrally symmetric<sup>8</sup> and centrally symmetric<sup>9</sup> crystals and, under favorable conditions, the effect can be greater in the former case. However, it appears to be simpler to observe in the second case because noncentrally symmetric crystals frequently exhibit the piezoelectric effect, and the thermopolarization effect can be masked by the so-

called third-order pyroelectric effect.<sup>10</sup> In centrally symmetric crystals, the larger effect is expected to occur where the permittivity is high, for example, in ferroelectrics in the paraphase. It has recently been observed experimentally<sup>11</sup> in one such crystal  $\text{PbMg}_{1/3}\text{Nb}_{2/3}\text{O}_3$ . The magnitude of the observed effect is in reasonable agreement with order-of-magnitude estimates offered by the theory.

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