$$< \tan\delta > \doteqdot \left\{ \tan^2\delta_1 + \frac{1}{2}A^2 \frac{(3\xi + 10\zeta P_s^2)^2}{(\xi + 2\zeta P_s^2)^2 \cos^2\delta_1} \right\}^{1/2}$$

$$= \tan\delta_1 \left\{ 1 + \frac{1}{2}A^2 \frac{(3\xi + 10\zeta P_s^2)^2}{(\xi + 2\zeta P_s^2)^2 \sin^2\delta_1} \right\}^{1/2} \quad (40)$$

The $\tan\delta_1$ is based on the fact that the phase of induced polarization P_E laggs behind that of the applied electric field, and corresponds to the loss tangent of normal dielectrics.

Now, let's deal with two kinds of transition by using above relationships:

(I) The second order transition

In the case of the second order transition, putting the relation $\zeta=0$ into eq. (40),

$$<\tan\delta> \doteqdot \sqrt{\tan^2\delta_1 + 9A^2/2\cos^2\delta_1} \quad (41)$$

By using relations $A=P_0/P_s$ and eq. (9), eq. (41) is rewritten as follows;

$$< \tan\delta > \doteqdot \sqrt{\tan^2\delta_1 - \frac{9}{2}P_0{}^2 \frac{\xi}{(u+gp)\cos^2\delta_1}} \quad (42)$$

The above equation shows the pressure dependence of $\tan\delta$. As the relationship between the spontaneous polarization P_s and the applied electric field E can be got by putting zero into ζ and P_s into P in eq. (3) and the relationship between the spontaneous polarization and the loss tangent is shown in eq. (41), the dc-electric field dependence of $\tan\delta$ can be obtained by combining these relationships as follows; under $\tan^2\delta_1 << 1$,

$$E = \left\{ u + gp + \xi\left(\frac{3}{\sqrt{2}} \frac{P_0}{\sqrt{\tan^2\delta - \tan^2\delta_1}}\right)^2 \right\} \frac{3}{\sqrt{2}} \frac{P_0}{\sqrt{\tan^2\delta - \tan^2\delta_1}} \quad (43)$$

To get the temperature dependence of **tan** δ, let us put eq. (12) into $A^2=(P_0/P_s)^2$ in the eq. (41), then the following equation can be obtained.

$$< \tan\delta > \doteqdot \sqrt{\tan^2\delta_1 - \frac{9}{2}P_0{}^2 \frac{\xi}{C_0(T-T_0)\cos^2\delta_1}} \quad (44)$$

Moreover, the dc-electric field dependence of $\tan\delta$ is calculated by modifying eq. (43), namely;

$$E = \left\{ C_0(T-T_0) + \xi\left(\frac{3}{\sqrt{2}} \frac{P_0}{\sqrt{\tan^2\delta - \tan^2\delta_1}}\right)^2 \right\} \frac{3}{\sqrt{2}} \frac{P_0}{\sqrt{\tan^2\delta - \tan^2\delta_1}}$$

(II) The first order transition

The pressure dependence of $\tan\delta$ in the case of the first order transition is shown in eq. (40). The value of $\tan\delta$ at the transition pressure and temperature in the first order transition is given by putting $[P_s^2]_{T_c}^{p_c} = -3\xi/4\zeta$ into P_s of eq. (40);

$$[\tan\delta]_{Tc,pc} \doteqdot \sqrt{\tan^2\delta_1 - 54P_0^2\zeta/\xi\cos^2\delta_1} \quad (45)$$

and the pressure dependence of $\tan\delta$ can be obtained by substituting eq. (21) for P_s of eq. (40);

$$< \tan\delta > \doteqdot \left[\tan^2\delta_1 - P_0^2 \frac{\zeta}{\xi} \frac{\left\{2 + 5\sqrt{1-(4\zeta/\xi^2)(u+gp)}\right\}^2}{\left\{1 + \sqrt{1-(4\zeta/\xi^2)(u+gp)}\right\}\left\{1-(4\zeta/\xi^2)(u+gp)\right\}\cos^2\delta_1} \right]^{1/2}$$

(46)

Furthermore, the temperature dependence of $\tan\delta$ is exhibited by modifying eq. (46) as follows;

$$<\tan\delta> \fallingdotseq \left[\tan^2\delta_1 - P_0^2 \frac{\zeta}{\xi} \frac{\left\{2 + 5\sqrt{1-(4C_0\zeta/\xi^2)(T-T_0)}\right\}^2}{\left\{1+\sqrt{1-(4C_0\zeta/\xi^2)(T-T_0)}\right\}\left\{1-(4C_0\zeta/\xi^2)(T-T_o)\right\}\cos^2\delta_1} \right]^{1/2} \qquad (47)$$

Now, let us apply the above mentioned analytical results to the experimental results of $NaNO_3$ which belongs to the second order transition and those of $BaTiO_3$ which belongs to the first order transition.

(1) The case of $NaNO_3$

The pressure dependence of tan δ is shown in Fig. 11. The loss tangent is not almost affected by the pressure in paraelectric phase, increases rapidly at the transition pressure and increases with pressure in ferroelectric phase. The loss tangent in ferroelectric phase decreases gradually with the dc-electric field as shown in Fig. 12.

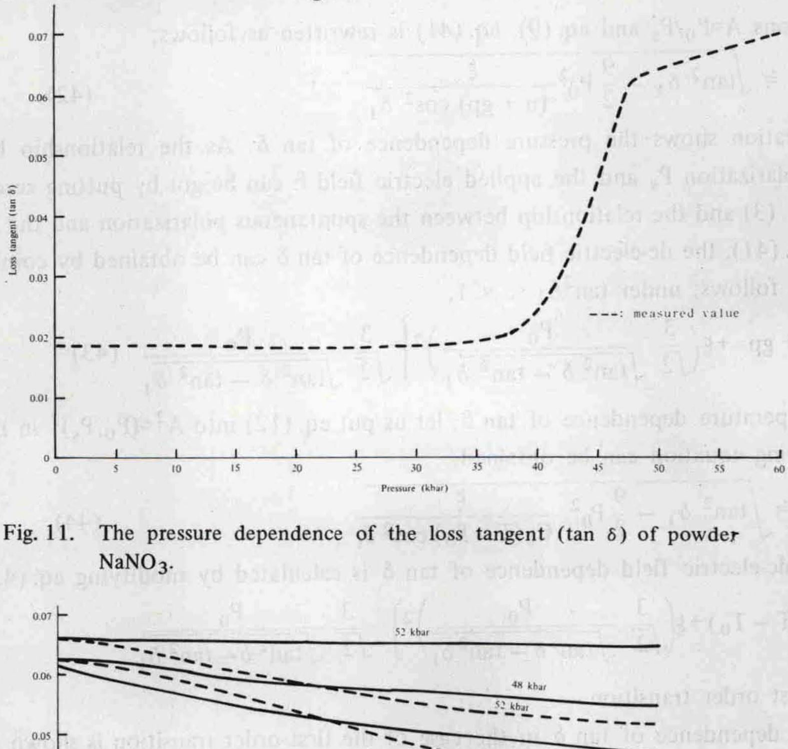

Fig. 11. The pressure dependence of the loss tangent (tan δ) of powder $NaNO_3$.

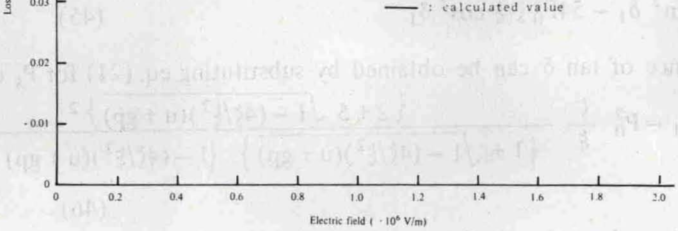

Fig. 12. Effect of external electric field on the loss tangent (tan δ) of powder $NaNO_3$ under various pressures.