Inverse Piezoelectric Properties of Rochelle Salt

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(Received June 20, 1934)

The relation between the change of lattice spacing of the (021) planes of Rochelle salt as a function of the change in voltage applied along the a-axis of the crystal has been determined by x-ray methods over the temperature range from approximately 10°C to 30°C. Measurements with a microscope of the strain set up in the crystal, due to a change in voltage applied along the a-axis, indicate that there is a one to one correspondence between the change of lattice constant as measured by x-rays and as determined from the measurements of strain. The piezoelectric modulus, d_{14}, as determined by the inverse piezoelectric effect is larger than the values determined from the piezoelectric effect.

THE strain corresponding to a change in electric stress along the a-axis of a Rochelle salt crystal has been measured.[1] There has been a question as to how this strain is distributed within the crystal, whether this displacement might take place in main between mosaic or a secondary lattice structure of the type postulated by Zwicky,[2] between any large groupings of molecules, or whether this displacement takes place chiefly in the primary lattice. A study of the change in the primary lattice constant, by means of x-rays, as a function of the change in voltage applied along the a-axis of the crystal together with measurements of the overall displacement of the crystal give sufficient information to answer the above question.

Rochelle salt crystals obtained from the Brush laboratories were cut into small rectangular blocks, one face being parallel to the (100) planes and another parallel to the (021). The lattice constants were taken as determined by Staub,[3] namely;

$$a=11.91\text{A};\quad b=14.32;\quad c=6.20.$$

Thus the normal to the (021) planes would make an angle of 40° 53′ with the b-axis, which is nearly the direction (45°) of greatest linear deformation within the crystal when the voltage is applied along the a-axis.

In order that a moist crystal might be dealt with, the crystals were kept in a bell jar that contained a saturated solution of Rochelle salt. When one was to be used it was taken from the bell jar, polished on a fine moist ground glass, and tin foil electrodes fastened to the crystal by means of a xylol Canada balsam solution so that the electric field would be along the a-axis. The crystal was then, together with a small cup of the saturated Rochelle salt solution, sealed in a controlled-temperature container, the x-rays entering and leaving this chamber through waxed paper windows. The x-ray camera consisted of an evacuated tube 103 cm in length from the slit to the plate. It was possible by an externally controlled screen within the camera to expose but half of the plate at a time. The procedure

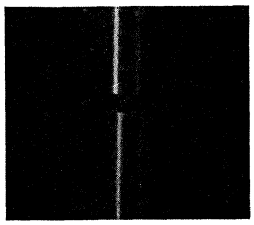


FIG. 1. Displacement of the copper $K\alpha_1$ and $K\alpha_2$ lines reflected from the (042) planes of Rochelle salt due to a voltage applied along the a-axis.

followed was to expose one-half of the plate with the voltage applied to the crystal in a given direction and to expose the other half of the plate with the voltage reversed. We would then obtain a picture (Fig. 1) with the lines on the upper and lower parts of the plate displaced slightly. This displacement is called $2\Delta s$ to correspond to the change of $2E_x$ in voltage. The time of exposure varied between 10 and 15 minutes using a 0.1 mm slit and $K\alpha_1$ and $K\alpha_2$ of copper excited by 10 m.a. at 28 kv.

[1] C. B. Sawyer and C. H. Tower, Phys. Rev. **35**, 269 (1930).
[2] Zwicky, Helv. Phys. Acta **3**, 466 (1930).
[3] Staub, Helv. Phys. Acta **7**, 3 (1934).

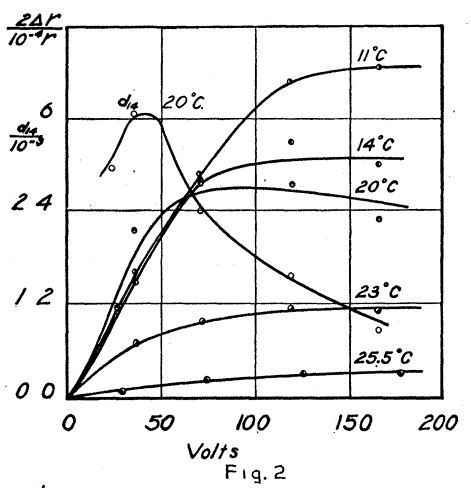


Fig. 2

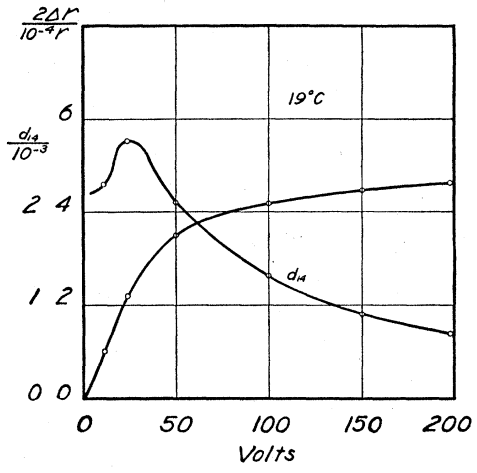


Fig. 3

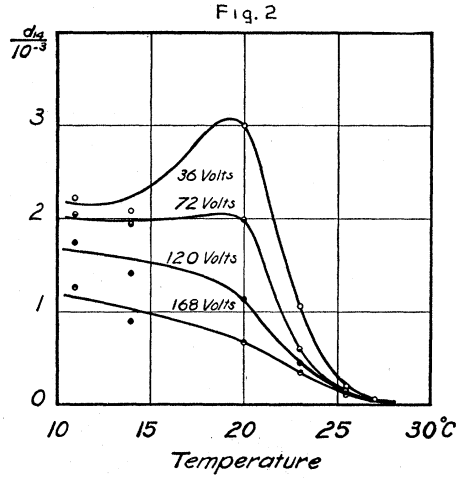


Fig. 4

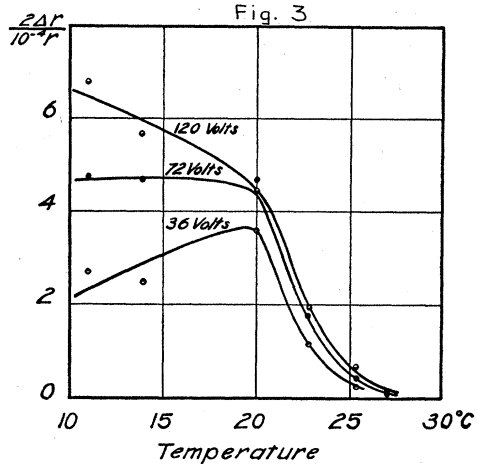


Fig. 5

FIG. 2. Relation between the lattice displacement and piezoelectric modulus as a function of voltage along the a-axis as determined from x-ray measurements.

FIG. 3. Relation between the lattice displacement and piezoelectric modulus as a function of voltage along the a-axis as determined by measurements of deformation made by means of a microscope.

FIG. 4. Piezoelectric modulus determined from x-ray measurements as a function of temperature.

FIG. 5. Lattice displacement determined from x-ray measurements as a function of temperature.

The measurement of this displacement was accomplished by aligning the negative in a comparator so that the cross hair of the comparator microscope, which is perpendicular to the screw, is parallel to the spectrum line, and so that the field of view of the microscope includes both the upper and lower lines of the negative. The displacement is measured within a few thousandths of a millimeter.

If $2\Delta r$ is the displacement of the crystal lattice in the direction of r due to a change in voltage from a positive value of E_x to an equal negative value of E_x, then it can be shown that

$$\Delta r/r = -\Delta s/2R \tan\theta,$$

where R is the distance between the camera slit and the plate and θ is the Bragg angle. The reflections were taken from the (042) planes which gave us an angle of 19° 10′.

Voigt[4] has shown that for a crystal of the

[4] Voigt, *Lehrbuch der Kristallphysik*, Chapter 8, Leipsig (1910).

symmetry of Rochelle salt the relations connecting the six strain components and electric field reduce to

$$y_z = d_{14}E_x; \quad z_x = d_{25}E_y; \quad x_y = d_{36}E_z;$$

y_z, z_x and x_y are strain components, d_{ij}, the piezoelectric moduli, and E_x, E_y, E_z the components of voltage along the respective axes. By the use of the proper equations of elasticity and with the voltage impressed along the a-axis it can be shown that the value of

$$d_{14} = -\Delta s/2RmnE_x \tan\theta,$$

m and n are the direction cosines with respect to the y and z axes of the normal to the $(0jk)$ plane considered. E_x is the voltage in e.s.u. along the a-axis of the crystal.

In Figs. 2–5 the displacements, $2\Delta r/r$, correspond to a change in the voltage from the value indicated to a negative potential of the same value. The temperature is kept constant within a few tenths of a degree throughout the time of exposure.

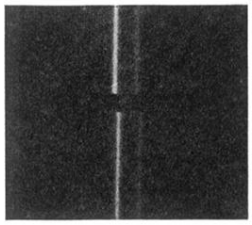
By comparison of Fig. 2 and Fig. 3 we see at once that the lattice displacement corresponds to the change in external dimensions of the crystal.

The results given by Sawyer and Tower[1] for the relation between strain and the peak electric field of a 60 cycle applied potential give results essentially the same as have been determined here, with the exception that a considerable voltage must be applied before the crystal shows an appreciable deformation, whereas the results given in this paper merely show a slight decrease in the slope of the strain voltage relations at the lower values of voltage. The reason for this difference is due to the sluggishness of response of the crystal at the lower voltages. The time required for the crystal to reach its maximum deformation may be of the order of several minutes for the small potentials, while for the higher values the maximum is reached so quickly that a sharp click is emitted. Frank C. Isely[5] has shown that for a given stress applied to a crystal, the crystal quickly reached an initial strain followed by a further gradual deformation lasting about fifteen seconds if the active faces of the crystal were short-circuited, and about twice that time if they were not. This might lead us to conclude that the effect is due to a conduction equalization of charges set up within the crystal by a non-uniform distribution of stress or strain. As the voltage applied became large the effect of these distributed charges would become negligible due to saturation effects.

The maximum value of d_{14} as calculated from the inverse piezoelectric effect is about forty times the maximum value, 8.1×10^{-5}, as calculated by Valasek[6] from the piezoelectric effect. The value of d_{14} is strongly a function of the moisture content of the crystal and of the stress applied, in the case of the direct effect, and of the voltage applied in case of the inverse effect. If the stress applied corresponds to a rather large value of voltage the difference in the piezoelectric modulus and the inverse piezoelectric modulus is of the order of ten times. It is quite likely that this difference is due in part to an "absorbed" charge caused by a gradual electrical polarization of the dielectric as a result of the long application of the voltage that was necessary for the x-ray measurements. The maximum strain in a crystal along the normal to the (021) planes due to an application of voltage along the a-axis, is larger by a factor of about two than the comparable strain as measured by Isely.[5] This is probably due to a difference in crystal.

It has been the privilege of the author to carry on this work under the supervision of Joseph Valasek.

[5] Frank C. Isely, Phys. Rev. **24**, 569 (1924).
[6] Valasek, Phys. Rev. **20**, 639 (1922).



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