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CHANGE IN THE ELASTICITY CONSTANTS OF SODIUM NITRATE DURING A PHASE TRANSITION OF THE SECOND KIND

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The temperature dependence of the elasticity coefficient of $NaNO_3$ crystals has been investigated in the temperature interval from 20 to 300° C. The change in these coefficients at 275.5° C, the point of a second-kind phase transition, has been noted.

IN theory of second-kind phase transitions usually only the change in the scalar quantities at the transition point is considered.[1] Yet in studying effects in crystals, tensor quantities are actually of the greatest interest. The purpose of the present investigation was to stimulate the development of theory in this direction.

For the specific subject of our investigation we chose crystals of $NaNO_3$, which according to Kracek[2] undergoes a transition of the second kind at 275.5° C and the quantity investigated was the set of elastic coefficients.

Sodium nitrate crystals belong to the rhombohedral system and six coefficients are necessary for a complete description of its elastic properties. These coefficients are commonly referred to a cartesian system of coordinates oriented in the crystal so that the z axis coincides with the third order symmetry axis, while the x axis is aligned with the second-order symmetry axis. The x and z axes together with the third coordinate axis (y) form a right-handed coordinate system in which the elasticity of the crystal is characterized by the coefficients s_{11}, s_{33}, s_{44}, s_{12}, s_{13}, and s_{14}.

As is known, application of a torque to a cylindrical single crystal specimen produces torsion in addition to bending, while the application of a tensile force produces shear in addition to elongation. These effects are absent only in specimens oriented along the crystallographic symmetry axes, i.e., in our case along the x and z axes. Having measured the speed of sound in such specimens with longitudinal and torsional oscillations one can directly find the four elasticity coefficients

$$s_{11} = 1/\rho c_x^2; \quad s_{33} = 1/\rho c_z^2; \quad s_{44} = 1/\rho c_z'^2; \qquad s_{12} = {}^1/_2 s_{44} + s_{11} - 1/\rho c_x'^2,$$

where c_x and c_z are the velocities of sound in longitudinal oscillations, c_x' and c_z' are the velocities of sound in torsional oscillations, and ρ is the density.*

To find the other coefficients one must work with samples whose axes do not coincide with the symmetry axes. In this case, in view of the above-mentioned effects, calculations become very complicated and the accuracy of determination is greatly impaired.[4] Hence we decided to forego determination of the coefficients s_{13} and s_{14} for the time being.

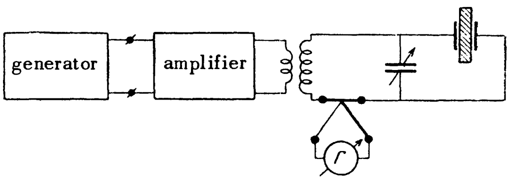

FIG. 1. Diagram of setup

The samples were prepared in the following manner. Rectangular bars of the requisite length and orientation were cut from large single crystals of chemically pure sodium nitrate grown from a melt by the method of Stober. The bars were ground down to a diameter of 5 mm (tolerance 0.01 – 0.04 mm) while held in a parabolic-section groove. The final determination of the orientation was made on a goniometer by measuring the angles between the axis of the rod and the cleavage planes. Only samples whose axes deviated less than 3° from the requisite crystallographic direction were accepted for further experimentation; the ends of these rods were ground off in a special holder.

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*The density of sodium nitrate at 20° C is 2.261.[3] The variation of the density with temperature can be found with the data given by Kracek.[2]

The speed of sound was measured by the "composite rod" method[5] following the procedure developed by one of the present writers.[6] The method consists of measuring the natural frequency of oscillation of a composite rod consisting of a cylindrical quartz piezocrystal and a sample of the same diameter cemented to its end. The velocity of sound in the sample (both with longitudinal and with torsional oscillations) is calculated by means of the formula $C = 2\pi f \ell / z$, where z is a root of the equation

$$\frac{\tan z}{z} = \frac{P \tan\left((n+1)\pi f/f_0\right)}{p \quad (n+1)\pi f/f_0}.$$

Here P is the weight of the quartz crystal, p the weight of the sample, ℓ the length of the sample, f_0 the natural frequency of oscillation of the quartz rod, f the natural frequency of the composite rod, and n the order of the harmonic.

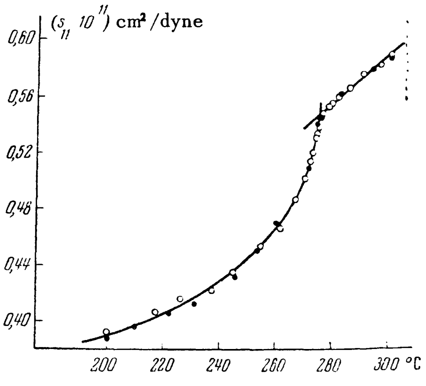

FIG. 2

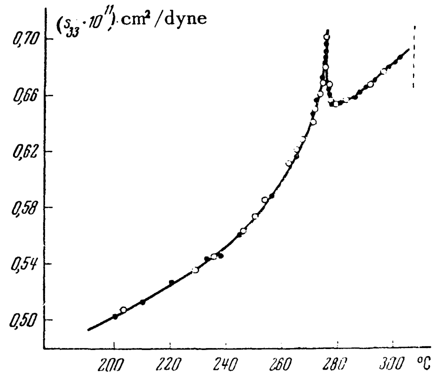

FIG. 3

We used cylindrical quartz rods 16 and 19 mm in length and 5.00 mm in diameter cut along the electric axis. The contact electrodes were applied chemically. Location of the electrodes was varied according to the mode it was required to excite. The samples were cemented to the quartz by means of an adhesive of water glass and talcum. The cement was allowed to set for a period of 2 hours at a temperature of 180° C and a pressure of 0.5 kg on the ends.

A holder of special design (located in a thermostatic chamber) clamped the quartz rod at the node and at the same time served to apply the voltage to the electrodes. The leads from the quartz-rod holder were connected to an oscillating tank circuit. The last was inductively coupled with a coil which was fed through an amplifier from a GSS-6 type standard signal generator. The current in the tank circuit was measured by a sensitive vacuum-thermocouple galvanometer connected between the capacitance and the inductance (Fig. 1).

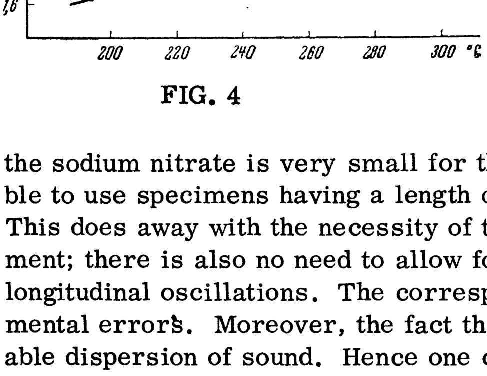

FIG. 4

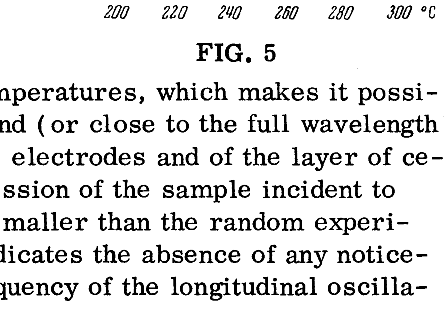

FIG. 5

The frequency of the tank circuit could be matched to the natural frequency of the composite rod by appropriate adjustment of the variable capacitor. Then as the frequency of oscillation of the generator is gradually changed the resonance curve of the circuit current exhibits a deep dip due to the sharp decrease in the impedance of the quartz rod at resonance. Measuring the frequency corresponding to the center of the dip with an accurate wavemeter, we obtain the natural frequency of the composite rod. The natural frequency of the quartz rod alone is determined in an analogous manner.

Preliminary tests showed that the absorption of sound in the sodium nitrate is very small for the entire range of investigated temperatures, which makes it possible to use specimens having a length of about half the wavelength of sound (or close to the full wavelength). This does away with the necessity of taking into account the mass of the electrodes and of the layer of cement; there is also no need to allow for the effect of transverse compression of the sample incident to longitudinal oscillations. The corresponding corrections proved to be smaller than the random experimental errors. Moreover, the fact that the absorption is very small indicates the absence of any noticeable dispersion of sound. Hence one can disregard the fact that the frequency of the longitudinal oscillations (~ 170 cps) differed somewhat from the frequency of the torsional oscillations (~ 120 cps).

The final results of the measurements are shown in the accompanying table and Figs. 2 through 5. The table lists the values of the elasticity coefficients obtained by smoothing and interpolation of the experimental curves in the temperature interval from 20 to 300° C. The figures show the variation of the coefficients in the temperature interval from 200 to 300° C, i.e., the vicinity of the phase transition point.

As can be seen from the figures the elasticity coefficients of an $NaNO_3$ crystal change in different manners at the phase transition point: the constant s_{33} exhibits a jump, while in the case of the coefficients s_{11}, s_{44}, and s_{12} only the derivatives with respect to the temperature show a true jump. As Dzialoshinskii and Lifshitz[7] showed, this fact is in agreement with the theory of one phase transition of the second kind.

°C	$(s \cdot 10^{11})$ cm²/dyne			
	s_{11}	s_{33}	s_{44}	s_{12}
20	0,32	0.42	1.18	—0,05
100	0,34	0.45	1,34	—0,04
150	0,36	0,47	1.45	-0.03_5
200	0,39	0.50	1,65	—0,02
230	0.41_5	0.54	1,86	0,00
250	$0,44_5$	0.57	2.07	$+0,01_5$
260	0.46_5	0.60	2,20	$+0.02_5$
270	0.50	0.64	2,48	+0.05
275.5	0.54_5	0.70	2.78	$+0,09_5$
280	0.55_5	0.65_5	2,82	+0.10
290	0.57	$0,66_5$	2.88	$+0,10_5$
300	0,59	0.68_5	2,95	+0,11

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[5] J. Stefan, Wiener Berichte 57, 697 (1868).

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POLARIZATION IN (p—p) SCATTERING AT 635 MEV

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The angular distribution of polarization arising in (p—p) scattering was studied in the range $11.6 \leq \theta \leq 90.3°$ (cms) by means of single and paired telescopes of scintillation counters. A proton beam of 635 Mev energy and polarization of 0.58 ± 0.03 was employed. An analysis of the results of measurement of the differential cross-sections $\sigma_0(\theta)$ for elastic scattering of 657 Mev unpolarized protons, was performed on basis of the optical model of (p—p) scattering with the aim of establishing the nature of interference between the Coulomb and nuclear scattering amplitudes. The polarization data can be satisfactorily approximated by a function of the form (9). The presence of the term $\sin\theta \cos\theta\, P_4(\cos\theta)$ in this formula indicates that triplet F-states play an important role in the scattering. It is found that at 635 Mev the polarization in quasi-elastic (p—p)-scattering by beryllium comprises about 85% of the polarization of protons scattered by hydrogen.

I. INTRODUCTION

IT is well known that the empirical facts examined by nuclear shell theory as well as the observations on the polarization of fast nucleons resulting from elastic scattering by nuclei are in general agreement with predictions based on the assumption that nuclear forces have a non-central character connected in