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Mechanical Properties of NaCl, KBr, KCl*

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The pulse method has been applied to measure mechanical properties of NaCl, KBr, and KCl at 10 and 30 Mc/sec. The elastic constants of KBr have been measured in the low temperature region. The strain-optical constants have been measured by a traveling-wave method suggested by Mueller.

I. INTRODUCTION

ONE result of the availability of electrical circuits for pulsing is that pulsed ultrasonic measurements have become practical. This method has some advantages over those previously used to determine the mechanical properties of solids. A traveling plane wave may be propagated through a sample of material in the form of a pulse of ultrasonic vibrations. Simple and direct measurements may be made on the echoes of such pulses as they travel back and forth in a medium in order to determine the elastic constants and the ultrasonic attenuation of the medium. Ultrasonic velocities, and therefore elastic constants, are determined from a direct measurement of the distance traveled by a pulse and the corresponding time. Attenuations are determined from the decrease in signal amplitude of successive echoes. Here again both distance and change in signal level are directly measured. At the start the pulse travels in a beam of finite cross section so that the sample is effectively infinite and no account need be taken of the possible effect of the cross-sectional dimensions of the sample. H. B. Huntington[1] has given a general description of the method used to measure elastic constants and attenuations in solids.

The stresses produced by the wave in the medium may also be determined by measuring the shunt impedance of the crystal and the amplitude of the applied voltage, since these quantities determine the power input during the pulse. The stress is obtained from the well-known relation that the sound intensity (power transmitted per unit area) is given by $X^2/2\rho v$, where X is the peak stress in the sound wave, ρ is the density of the material, and v is the velocity of propagation of the wave.

It is also quite easy to measure the ratios of the strain-optical constants (p_{ik}) of a material by the use of pulsed ultrasonics. These ratios determine the polarization of the light diffracted by ultrasonic waves in a crystal. Mueller[2] has described the method used (his method B). In these cubic crystals we measure p_{12}/p_{11} and $p_{44}/(p_{11}+p_{12})$ this way.

Perhaps the most important advantage of the method, especially for the strain-optical constant measurements where a block of substantial size must be used, is the fact that we are dealing with plane elastic wave fronts. Very nearly plane waves can be produced in a large sample by making the dimensions of the radiating surface many wave-lengths long. Thus the difficulties of producing standing waves with a single set of parallel nodal planes and the influence of the boundary conditions are avoided, and our experimental conditions approach more closely the ideal conditions of the theory than is possible when a block is set in vibration as a resonator.

In order to obtain a short pulse which is still several wave-lengths long, almost all the measurements in the present research were made at a frequency of approximately 10 Mc/sec. Some elastic constant and attenuation measurements were made at 30 Mc/sec also.

II. ELASTIC CONSTANTS

The adiabatic elastic constants c_{ik} of a cubic crystal are determined from the density and the velocities of three plane waves. These are first, a compressional wave propagated along the cube

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[1] H. B. Huntington, Phys. Rev. 72, 321 (1947).

[2] H. Mueller, Zeits. f. Kristallographie (A)99, 122 (1938).

axis, with a velocity of $(c_{11}/\rho)^{\frac{1}{2}}$; second, a shear wave propagated along the cube axis with a velocity of $(c_{44}/\rho)^{\frac{1}{2}}$, and third, a shear wave propagated in the 110 direction with a velocity of $[(c_{11}-c_{12})/2\rho]^{\frac{1}{2}}$.

Measurements of the elastic constants at room temperature have been made on NaCl, KBr, and KCl. The data are presented in Table I along with that obtained by Huntington[1] and Durand.[3]

It is felt that the agreement between the present measurements and those of Huntington illustrates the accuracy obtainable with the present method. These measurements were made on different samples and were otherwise quite independent. The disagreement with the values of Durand for NaCl is larger than the error estimated for the pulsed measurement.

The elastic constants of KBr have been measured over the low temperature range. Refrigeration was obtained with a Collins helium cryostat.[4] The data are shown in Figs. 1 and 2. The data on c_{12} extend only down to 138°K. Cracks occurred in the sample at an angle of 45° to the direction of propagation of the wave and destroyed the echo pattern at temperatures below this. This cracking is the result of stresses produced by the differential thermal contraction between the quartz crystal and the alkali halide. The cleavage planes are parallel to the direction of propagation of the waves used to measure c_{11} and c_{44}, however, so that these measurements could be extended to 4.5°K even though some cracking occurred.

TABLE I. Elastic constants measured at room temperature (units are dynes/cm²).

		NaCl	KBr	KCl
$c_{11}\times10^{-11}$	Galt	4.87	3.46	3.98
	Huntington	4.85	3.45	
	Durand	4.99		4.00 (extrapolated to 300°K)
$c_{12}\times10^{-11}$	Galt	1.24	0.58	0.62
	Huntington	1.23	0.54±0.03	
	Durand	1.31		0.6
$c_{44}\times10^{-11}$	Galt	1.26	$0.50\underline{5}$	0.625
	Huntington	1.26	0.508	
	Durand	1.27		0.631 (extrapolated to 300°K)

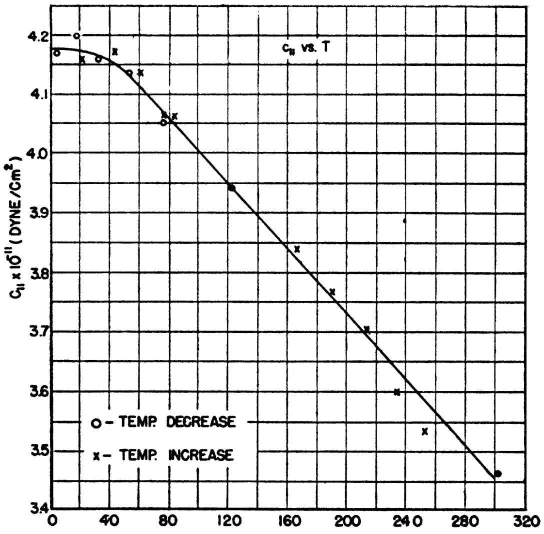

FIG. 1.

The variation in the density of the sample with temperature was corrected for down to 90°K. It was assumed constant below this temperature, as no measurements of expansion coefficient are available there.[5]

For the low temperature measurements the quartz was cemented to the sample with a cement made of a mixture of natural rubber and vaseline.

The zero slope of these curves at 0°K may easily be derived from the Maxwell relation $(\partial X_i/\partial T)_{x_i}=(\partial S/\partial x_i)_T$ (where X_i is a stress, and x_i the strain) and the Nernst theorem in thermodynamics, from which we have $\partial S/\partial x_i=0$ at 0°K.[6]

One source of error in the elastic constant measurements is pulse distortion. At room temperature this is caused by the fact that reflections occur at both sides of the cement film which affixes the quartz crystal to the alkali-halide sample. In the low temperature range it is increased by the adjustments which the film must make to compensate for the differential thermal contraction between the quartz crystal and the alkali halide. A small amount of error may occur in calibrating the sweep of the oscil-

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[3] M. A. Durand, Phys. Rev. **50**, 449 (1936).

[4] S. C. Collins, Rev. Sci. Inst. **18**, 157 (1947).

[5] A. Henglein, Zeits. f. physik. Chemie **115**, 91 (1925).

[6] The author is greateful to Professor L. Tisza and Dr. C. Kittel for pointing out these relations to him.

TABLE II. Strain-optical constant ratios.

Substance		p_{12}/p_{11}	$p_{44}/(p_{11}+p_{12})$	p_{44}/p_{11}
NaCl	Galt	1.35 ± 0.03	-0.042 ± 0.004	-0.099
	Pockels	1.30	-0.0343	-0.079
KCl	Galt	0.76 ± 0.01	-0.069 ± 0.004	-0.12
	Pockels	0.74	-0.069	-0.12
KBr	Galt	0.77 ± 0.01	-0.067 ± 0.005	-0.12

loscope used to measure the time required for the mechanical wave to travel through the sample. The largest error in the low temperature measurements is the uncertainty in measuring the temperature of the sample because of temperature gradients in the cryostat. The error in measuring temperature may be as high as several degrees. It is felt, however, that the curves drawn in Figs. 1 and 2 for c_{11} and c_{44} are accurate to better than 1 percent. The c_{12} curve may be in error by a somewhat larger amount since c_{12} is determined by subtracting two larger numbers. The variations indicated by the plots of Figs. 1 and 2 have a much smaller absolute error than the values of the elastic constants themselves, of course.

III. ATTENUATION

The attenuations of all the waves mentioned above were also measured. The attenuation α of a wave, which has traveled a distance x and in which the peak stress is X, may be defined by the relation:

$$X = X_0 e^{-\alpha x}.$$

All shear waves in all crystals have measured α's between 0.004 and 0.005 cm^{-1}. The compressional waves have α-values between 0.001 and 0.002 cm^{-1}. In view of this lack of variation it is felt that these values may only be considered as upper limits. Measurements made on shear waves in NaCl at 30 Mc gave the same value of attenuation.

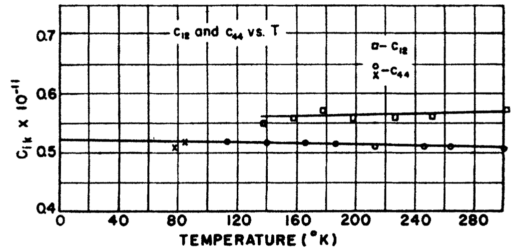

FIG. 2.

IV. STRAIN-OPTICAL CONSTANTS

When light is diffracted by ultrasonic waves in a crystal, its polarization is changed as well. This change can be measured by first crossing analyzer and polarizer while no elastic waves are excited in the crystal, and then noting the change of the analyzer required to extinguish successive diffraction orders of the Debye-Sears pattern when ultrasonic vibrations are excited. If the ultrasonic wave travels vertically along the 100 direction, and the incident light is polarized at +45° to the horizontal, this change in polarization measures p_{12}/p_{11} in a cubic crystal.[2] If the ultrasonic wave travels along the 110 direction and the other conditions are the same, this change in polarization[2] measures $p_{44}/(p_{11}+p_{12})$. Table II gives the strain-optical constants measured and also p_{44}/p_{11}, as determined from p_{12}/p_{11} and $p_{44}/(p_{11}+p_{12})$. For the ratios which were measured, an estimate of the error is given. This estimate is based on the reproducibility of the measurement of the angle at which the diffracted light is crossed out. No large permanent strains were present in the samples and there were no apparent systematic errors. Pockel's data for KCl and NaCl are presented for comparison.

The values in Table II are consistent with the predictions of Mueller's theory.[7] In particular they bear out his prediction that the values for KBr and KCl are the same.

The author wishes to express his gratitude to Professor D. C. Stockbarger for providing the alkali-halide crystals on which the measurements were made. He wishes especially to express his sincerest thanks to Professor H. Mueller, under whose direction this research was carried out.

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[7] H. Mueller, Phys. Rev. **47**, 947 (1935).