

TABLE I. Smooth-curve values at one atmosphere of the adiabatic elastic constants  $c_{11}$ ,  $c_{44}$ , and  $C'$  and calculated values of  $1/\beta^s$  for  $\text{NH}_4\text{Br}$  in the cubic disordered phase, all in units of  $10^{11}$  dyn  $\text{cm}^{-2}$ .

$T(^{\circ}\text{K})$	$c_{11}$	$c_{44}$	$C'$	$1/\beta^s$
235	...	0.7992	1.3110	...
236	...	0.7987	1.3171	...
237	3.2640	0.7977	1.3205	1.5033
238	3.2860	0.7968	1.3231	1.5219
240	3.3190	0.7948	1.3260	1.5510
245	3.3694	0.7897	1.3292	1.5971
250	3.3942	0.7842	1.3300	1.6209
260	3.4205	0.7726	1.3289	1.6486
270	3.4293	0.7605	1.3264	1.6608
280	3.4293	0.7478	1.3232	1.6650
290	3.4236	0.7349	1.3197	1.6640
300	3.4144	0.7218	1.3160	1.6597
310	3.4028	0.7083	1.3122	1.6532
320	3.3885	0.6944	1.3083	1.6441

As the temperature was lowered toward the transition temperature, an increase in attenuation was observed. For longitudinal waves in the [100] and [110] direction and for the transverse wave which yields  $C'$ , the attenuation increased rapidly at the transition temperature and the echoes completely disappeared. As the temperature was lowered below 210°K, echoes slowly began to reappear. The shape of these echoes was very poor, and there was still a great deal of attenuation. Thus it was not possible to make meaningful velocity measurements for  $c_{11}$  and  $C'$  below the transition.

For the transverse waves associated with  $c_{44}$  there was only slight attenuation in the critical region, and data could be obtained over the entire temperature range 100°–320°K including the immediate vicinity of  $T_{\lambda}$ . Values of  $c_{44}$  were determined between 215° and 235°K on all three crystals (using both [100] and [110] propagation directions) and good agreement was obtained. This lends support to the idea that there are small domains with their tetragonal axes randomly oriented along the  $x$ ,  $y$ , or  $z$  axes of the original cubic crystal. In that case, the measured  $\rho U_t^2$  values below the transition point correspond to an average shear

TABLE II. Smooth-curve values of the adiabatic quantity  $\rho U_t^2 = \bar{c}_{44}$  for  $\text{NH}_4\text{Br}$  in the tetragonal (ordered) phase at 1 atm, in units of  $10^{11}$  dyn  $\text{cm}^{-2}$ .

$T(^{\circ}\text{K})$	$c_{44}$	$T(^{\circ}\text{K})$	$c_{44}$
110	0.7713	205	0.7273
120	0.7639	210	0.7297
130	0.7567	215	0.7331
140	0.7496	220	0.7386
150	0.7427	225	0.7481
160	0.7364	230	0.7627
170	0.7307	231	0.7680
180	0.7265	232	0.7725
190	0.7244	233	~0.778
200	0.7258	234	~0.79

constant  $\bar{c}_{44}$  which is related to the single-crystal tetragonal constants by  $\bar{c}_{44} = \frac{1}{3}(2c_{44} + c_{66})$ . Values of  $\rho U_t^2 = \bar{c}_{44}$  obtained from measurements along a [100] direction (in the original cubic crystal) are given in Table II and shown in Fig. 4.

Although it is not shown in Fig. 4, hysteresis was observed in the temperature behavior of  $c_{44}$ . On cooling the sample a sharp drop in  $c_{44}$  occurred at 234.2°K, whereas the most rapid jump in the  $c_{44}$  value on warming the sample occurred at 234.8°K. This temperature hysteresis of 0.6°K is quite comparable to the hysteresis of 0.9°K observed for both  $c_{44}$  and  $C'$  in ammonium chloride.<sup>12</sup>

The greatest sources of error in these elastic constants at 1 atm are due to uncertainties in the path lengths at 20°C ( $\pm 0.1\%$ ) and ambiguities in the choice of the  $n=0$  condition<sup>12</sup> for shear waves (especially for  $c_{44}$ ). Therefore, to check the possibility that a wrong  $n=0$  value had been chosen and also to check the internal consistency of our data, the velocity of the longitudinal

TABLE III. The adiabatic elastic constants and bulk modulus of ammonium bromide single crystals at room temperature obtained from the present measurements (P) compared with the results obtained by Haussuhl (H) and by Sundara Roa and Balakrishnan (S and B); the bulk modulus of polycrystalline ammonium bromide obtained by Bridgman (B) is included. All values are given in units of  $10^{11}$  dyn  $\text{cm}^{-2}$ .

Obs.	$T(^{\circ}\text{K})$	$c_{11}$	$c_{44}$	$C'$	$c_{12}$	$1/\beta^s$
P	300	3.414	0.722	1.316	0.782	1.66
H	293	3.38	0.685	1.24	0.91	1.73
S and B	298	2.96	0.53	1.19	0.59	1.38
B	298	...	...	...	...	1.63

wave in the [110] direction was measured as a function of temperature. The experimental value of  $\rho U_t^2$  for this wave and that calculated from Eq. (4) using the tabulated values of  $c_{11}$ ,  $c_{44}$ , and  $C'$  were within 0.1 percent of each other over the entire temperature range 250°–300°K. This eliminates the possibility of a systematic error in the choice of the  $n=0$  value for  $C'$ . For  $c_{44}$  there is still a possibility that the reported values may be systematically in error by  $\pm 0.9\%$ . A propagation-of-errors treatment indicates that the random error in all three elastic constants is about  $\pm 0.2\%$  at all temperatures.

The independent adiabatic elastic constants of single-crystal ammonium bromide at room temperature have been measured by Sundara Roa and Balakrishnan<sup>19</sup> and by Haussuhl,<sup>20</sup> who also measured the temperature dependence down to the transition. Table III gives a comparison of the elastic constants and the bulk modulus obtained by these investigators with the results

<sup>19</sup> R. V. G. Sundara Rao and T. S. Balakrishnan, Proc. Ind. Acad. Sci. **28A**, 480 (1948).

<sup>20</sup> S. Haussuhl, Acta Cryst. **13**, 685 (1960).