TABLE I. Effective stiffness constant equations and experimental antimony velocities.

Eq. No.	Effective stiffness constant equations (ρ, the material density)	Direction cosines of propagation vector	Direction cosines of transducer polarization	Experimental velocity 10^5 cm/sec
(1)	$\rho v_1^2 = c_{11}$	100	100	$3.92\pm2\%$
(2)	$\rho v_2^2 = \frac{1}{2}[(c_{66}+c_{44})+\{(c_{44}-c_{66})^2+4c_{14}^2\}^{1/2}]$		001	$3.00\pm1.5\%$
(3)	$\rho v_3^2 = \frac{1}{2}[(c_{66}+c_{44})-\{(c_{44}-c_{66})^2+4c_{14}^2\}^{1/2}]$		010	$1.53\pm2.6\%$
(4)	$\rho v_5^2 = c_{66} = \frac{1}{2}(c_{11}-c_{12})$	010	100	$2.23\pm1.5\%$
(5)	$\rho v_4^2 = \frac{1}{2}[(c_{11}+c_{44})+\{(c_{44}-c_{11})^2+4c_{14}^2\}^{1/2}]$		010	$3.98\pm1.7\%$
(6)	$\rho v_6^2 = \frac{1}{2}[(c_{11}+c_{44})-\{(c_{44}-c_{11})^2+4c_{14}^2\}^{1/2}]$		001	$2.24\pm2\%$
(7)	$\rho v_7^2 = c_{33}$	001	001	$2.60\pm1.2\%$
(8)	$\rho v_8^2 = c_{44}$		100 or 010	$2.45\pm1.2\%$
(9)	$2\rho v_9^2 = \frac{1}{2}(c_{11}+c_{33})+c_{44}-c_{14} +\{(\frac{1}{2}c_{11}-\frac{1}{2}c_{33}-c_{14})^2+(c_{13}+c_{44}-c_{14})^2\}^{1/2}$	$0, 1/\sqrt{2}, 1/\sqrt{2}$	$0, 1/\sqrt{2}, 1/\sqrt{2}$	$3.12\pm1.9\%$
(10)	$2\rho v_{11}^2 = \frac{1}{2}(c_{11}+c_{33})+c_{44}-c_{14} -\{(\frac{1}{2}c_{11}-\frac{1}{2}c_{33}-c_{14})^2+(c_{13}+c_{44}-c_{14})^2\}^{1/2}$		$0, -1/\sqrt{2}, 1/\sqrt{2}$	$1.25\pm1\%$
(11)	$\rho v_{10}^2 = \frac{1}{2}(c_{66}+c_{44})+c_{14}$		100	$2.87\pm4.1\%$
(12)	$\rho v_{13}^2 = \frac{1}{2}(c_{66}+c_{44})-c_{14}$	$0, -1/\sqrt{2}, 1/\sqrt{2}$	100	$1.54\pm10\%$
(13)	$2\rho v_{12}^2 = \frac{1}{2}(c_{11}+c_{33})+c_{44}+c_{14} +\{(\frac{1}{2}c_{11}-\frac{1}{2}c_{33}+c_{14})^2+(c_{13}+c_{44}+c_{14})^2\}^{1/2}$		$0, -1/\sqrt{2}, 1/\sqrt{2}$	$4.14\pm1.8\%$
(14)	$2\rho v_{14}^2 = \frac{1}{2}(c_{11}+c_{33})+c_{44}+c_{14} -\{(\frac{1}{2}c_{11}-\frac{1}{2}c_{33}+c_{14})^2+(c_{13}+c_{44}+c_{14})^2\}^{1/2}$		$0, 1/\sqrt{2}, 1/\sqrt{2}$	$1.50\pm6\%$

tioned as the transmitting and receiving transducer. Measurements were taken between 5 and 70 Mc. The frequency which gave the sharpest pattern for a particular mode is the one at which the velocity was measured. These best frequencies were scattered throughout this range. More than one frequency gave a decipherable pattern for a given mode, but most frequencies did not. It was, however, possible to obtain a crude check of the frequency dependence of v_7. This result together with qualitative results for other modes at two frequencies show no frequency dependence within the specified experimental tolerances.

Salol was used to bond the transducer to the specimen surface which was either a natural cleavage surface, the (111) plane, for slab specimens, or a comparatively rougher spark-cut surface for the two specimens whose velocities were actually used to obtain the constants. The slab specimens, cleaved at opposite faces and of varying thickness and width, were used primarily to check the effect of spark-cut surfaces on the coupling of energy into and out of the specimens and on the reflection of energy at the back surface into the specimen. No deleterious effects of spark cutting were seen. Another experimental check is that our values for v_1, v_4, and v_7 are within 4% of Eckstein's[10] 77°K velocities which are, respectively, 3.85, 4.08, and 2.58 10^5 cm/sec.

Zone-refined antimony, Cominco Grade 69, 99.999% pure, was the stock for our slabs and cubes. (Initially, stock which was very likely less pure was used and at the few points where checks were made yielded essentially the same results.)

The two differently oriented single-crystal cubes, 12 mm on edge, were prepared by spark cutting[11] their faces within $\pm1°$, as required for our experimental design. Strains were checked for by x-ray diffraction.

Back-reflection Laue diagrams were used to choose the positive X, Y, and Z axes directions. They were indexed by identifying spots belonging to the $\langle 01\bar{1}\rangle$ zone (in the mirror plane) on each side of the (111) pole (see Fig. 1)—in particular, the $(3\bar{1}\bar{1})$, $(4\bar{1}\bar{1})$, $(5\bar{1}\bar{1})$, (100), (011), and $(\bar{1}11)$ spots. (These indices are based on the large, nearly cubic, rhombohedral cell containing 8 atoms; the notation is Vickers.)[12]

Part of Vickers' stereogram is reconstructed in Fig. 1 in order to show the relative positions of the secondary cleavage plane to the axes. This plane was positively identified by comparing the angle between the secondary cleavage plane and the (111) plane as measured on cleaved specimens, firstly with the estimated angle the (011) spot makes with the (111) spot, and next with the value for this angle given by Dana.[5] Our observations of secondary cleavages on many antimony rods and slabs show this plane to be easily observable and to slant in a unique direction. Accordingly, a convenient way of identifying the right-handed coordinate system used in the crystal is shown in Fig. 1. With the planes sloping downward to the right, the positive Y axis is directed from left to right, positive X toward the observer, and positive Z upward.

V. EXPERIMENTAL ANALYSIS AND RESULTS

Our velocity values, shown in Table I, represent averages of the average velocity calculated from meas-

[10] Y. Eckstein, Phys. Rev. 192, 12 (1963).

[11] H. J. Ehlers, D. F. Kolesar, Rev. Sci. Instr. 34, 1054 (N) (1963).

[12] W. Vickers, J. Metals 9, 827 (1957).