Table 3. Comparison of 4·2°K elastic constants and adiabatic bulk modulus in units of 10^{11} dyne cm^{-2}

Investigator	C_{11}	C_{12}	C_{44}	B_s
Authors	5·834	1·192	1·337	2·739
LEWIS *et al.*[8]	5·733	1·123	1·331	2·660
OVERTON and SWIM[3]	5·750	0·986	1·327	2·574

power series with the leading term being proportional to T^4, which gives a T^3 leading term to the linear expansion coefficient. Coupling this result with the Debye temperature, θ_D, the molar volume, V, and the bulk modulus, B_s, he calculates the Gruneisen parameter γ_0 corresponding to the low temperature T^3 region. White used the bulk modulus determined by OVERTON and SWIM[3] with the result that $\gamma_0 = 0{\cdot}90 \pm 0{\cdot}03$. The present measurement of the bulk modulus is 6·6% higher than Overton and Swim's value and increases γ_0 to $0{\cdot}96 \pm 0{\cdot}03$.

In terms of the microscopic parameters[10] of the crystal, the Gruneisen parameter is given by

$$\gamma = \frac{\sum_i c_i \gamma_i}{\sum_i c_i}, \tag{5}$$

where c_i is the Einstein heat capacity of the i^{th} normal mode. In the T^3 region of temperature, one may assume the crystal to behave like an elastic continuum with the weighting factors in the above expression being replaced by $C_i^{-3/2}$, the elastic constant for the i^{th} branch in the direction θ, ϕ, and the above equation goes over to the following integral form

$$\bar{\gamma}_L = \frac{\sum_{i=1}^{3} \int_\Omega \gamma_i C_i^{-3/2}\, d\Omega}{\sum_{i=1}^{3} \int \gamma_i C_i^{-3/2}\, d\Omega} \tag{6}$$

where $d\Omega$ is the element of solid angle. The γ_i for low frequency modes can be calculated from the pressure derivatives of the elastic constants as described by various authors.[10] The above integral has been calculated for temperatures of 295°K and 195°K using the low temperature elastic constants reported in Table 3 along with the pressure data of BARTELS.[4] These results, along with a volume extrapolation to 0°K as predicted by the Quasi Harmonic Approximation, are listed in Table 4. Bartels obtained an extrapolated value of 1·05, using Overton and Swim's low temperature elastic data, as compared to the authors' value of 1·06. There are two main reasons why $\bar{\gamma}_L$ was insensitive to the changes in the low temperature elastic constants. First, the weighting factors occur in both the numerator and denominator in the expression for $\bar{\gamma}_L$ and thus a slight change

Table 4. $\bar{\gamma}_L$ for NaCl calculated from the mode gammas compared with White's Thermodynamic value of γ_0

	295°K	195°K	0°K	White
$\bar{\gamma}_L$	1·17	1·12	1·06	$0{\cdot}96 \pm 0{\cdot}03$
$\frac{V_{295} - V}{V_{295}}$	0	0·0112	0·0232	

The values of $\bar{\gamma}_L$ listed under 295°K and 195°K were calculated from the mode gammas at those temperatures and were 'volume extrapolated' to give the value listed under 0°K. This latter value can be considered to be calculated from the 0°K mode gammas and is the one that should be compared with White's value. Also given are the relative volume changes that were used. V is the volume at the temperature under consideration and V_{295} is the volume at 295°K.

in them tends to cancel. Second, the transverse mode corresponding to C_{44} carries the largest weighting since it is the lowest velocity mode, and the measured value of C_{44} reported by Overton and Swim differs with the authors' value by less than one per cent.

The Debye temperature, θ_D, can be calculated from the value of the integral which appears in the denominator of the expression for $\bar{\gamma}_L$. The data of Overton and Swim gives a value of 322·3°K, while the present data yields a value of 322·0°K. This slight effect upon θ_D is due to the fact that the dominant mode in determining θ_D is C_{44}.

The main effect of the present measurements has been to increase the low temperature bulk modulus and also the measured low temperature Gruneisen parameter by about 7%, while leaving the calculated Gruneisen parameter, $\bar{\gamma}_L$, essentially unchanged.

Acknowledgement—This work was supported by the Atomic Energy Commission.

REFERENCES

1. Leibfried G. and Ludwig W., *Solid St. Phys.* (editors Seitz F. and Turnbull D.) **12**, 275. Academic Press, New York (1961).
2. White G. K., *Proc. R. Soc.*, **A286**, 204 (1965).
3. Overton W. C. and Swim R. T., *Phys. Rev.* **84**, 758 (1951).
4. Bartels R. A. and Schuele D. E., *J. Phys. Chem. Solids* **26**, 539 (1965).
5. Daniels W. B. and Smith C. S., *The Physics and Chemistry of High Pressures*, p. 50. Soc. of Chem. Industry, London (1963).
6. Meincke P. P. M. and Graham G. M., *Eighth Int. Conf. on Low Temp. Phys.* (to be published).
7. *National Bureau of Standards Circular* **539, 2,** 41 (1953).
8. Lewis J. T., Lehoczky A. and Briscoe C. V., *Bull. Am. Phys. Soc.* Vol. **10**, no. 1, p. 44.
9. McSkimin H. J., *J. Acoust. Soc. Am.* **33**, 12 (1961).
10. Sheard F. W., *Phil. Mag.* **3**, 1381 (1958).

Note added in proof—P. P. M. Meincke and G. M. Graham [*Can. J. Phys.* **43**, 1853 (1965)] recently reported thermal expansion data on NaCl. Their technique involves the use of a Fabrey–Perot etalon dilatometer and for NaCl in the region below 12°K they fitted their experimental points with $\alpha = 6{\cdot}1 \pm 0{\cdot}1$ T^3/°K; which results in a $\gamma_0 = 1{\cdot}06$. Using the authors' bulk modulus data raises their value of γ_0 to 1·13.