

TABLE I.

T in °K:	1.6°	1.8°	2.0°	2.1°	2.2°	2.4°	3°	4°
η_4 in μP :	0.18	0.35	0.80	1.5	15	22	25	28
$\Delta\eta/\eta_4$:	0.35	0.18	0.079	0.042	0.0042	0.0029	0.0025	0.0022

$$\begin{aligned} \bar{E} &= (3h^2/10m)(3\rho/8\pi m)^3, \\ \epsilon &= (2\bar{E}/m)^{1/2} = (h/m)(3/5)^{1/2}(3\rho/8\pi m)^{3/2}. \end{aligned} \quad (5)$$

For ρ/m we may take the value given by Eq. (3) since we should take for the volume available per He_3 atom the free volume of one atom in the liquid. The density of liquid He_4 does not change appreciably over the whole range of possible temperatures. We shall assume $\rho_4 = 0.145 \text{ g/cm}^3$. Since the mean free path l is equal to $m/\sqrt{2}\pi\rho d^2$, where d is the diameter of the atoms involved, we have for η_3^{kin} from Eqs. (2), (3), and (5):

$$\eta_3^{\text{kin}} = (h/\pi d^2)(30)^{-1/2}(3\rho_4/8m_4)^{3/2} = 6.3\mu P, \quad (6)$$

with $d = 2.9\text{Å}$.²

Using Eq. (6), expression (4) for the change in viscosity and the experimental values of ρ_4 given in Keesom's monograph,³ it is possible to calculate the percentage changes in viscosity. For $x = 0.01$, these changes are for different temperatures (see Table I).

It must be remarked that the values in the table are lower estimates. There are two reasons why the effect may well be higher. Firstly, the Maxwell tail of the Fermi distribution may give rise to a slightly higher value of ϵ . Secondly, He_3 may well have a dynamic viscosity below 2.2°K since its λ -point, if it exists, will probably occur for a lower temperature. The higher viscosity of the mixture, however, might perhaps under certain conditions of flow be partly concealed by a lubricating effect of the He_4 . Finally, we must remark that even if He_3 should show a λ -transition, which could, e.g., be observed in the specific heat curve, no superfluidity or large heat conductivity would be present due to the Fermi-Dirac viscosity, given by Eq. (6)

¹ L. Tisza, Phys. Rev. **72**, 838 (1947).

² W. H. Keesom, *Helium* (Elsevier Publishing Company, Amsterdam, 1942), p. 50 and following pages.

³ See reference 2, p. 267, Fig. 6.03; p. 271, Table 6.02.

On the Nuclear Electric Quadrupole Moment of Li^6

P. KUSCH

Columbia University, New York, New York
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THE line observed in the molecular beam magnetic resonance method, and which results from the re-orientation of the nuclear spin with respect to an applied magnetic field, is the envelope of a large number of closely spaced lines arising in the rotational states, J, m_J . Feld and Lamb¹ have shown that the effect of a quadrupole moment of one of the nuclei in a heteronuclear diatomic molecule at sufficiently high fields is to introduce into this envelope $2I$ equally spaced maxima, each maximum corresponding to a particular transition m_I to $m_I \pm 1$. The

maxima are symmetrically disposed about the frequency $g\mu_0 H/h$. From the separation of the maxima it is possible to determine the quadrupole interaction energy, e^2qQ .

Whether or not the maxima are observable depends on a number of factors which include the inherent width of the maxima as determined by the interaction of the quadrupole moment with the molecular rotation, the interaction of the magnetic dipole moment with the molecular rotation, and the resolution of the molecular beam apparatus.

The spectra of all the lithium halides have been observed at a field of about 11,000 gauss. At this field the Li^7 line occurs at a frequency of about 9.6 mc/sec. and all second- and higher order terms in the quadrupole interaction energy may be ignored. The line of Li^7 in all of the lithium halides shows the characteristic structure predicted by Feld and Lamb. Three peaks occur, and the frequency separation of the two extreme peaks, $e^2qQ_7/2h$, is given for the case of the four lithium halides in the second column of Table I. The width of the central maximum, which is a measure of the interaction of the nuclear moment with the magnetic field of the molecular rotation, is given in the third column of Table I.

The line of Li^6 , where $I = 1$, should consist of two components whose separation is $3e^2qQ_6/4h$. Evidently, since the same value of q occurs for either isotope in a given molecule, and since the separation of the peaks is substantially the same for Li^7 in LiCl , LiBr , and LiI , it is to be expected that the separation of the two peaks in the molecules containing Li^6 should also be the same. However, the line of Li^6 in three lithium halides appears as a single line whose width is given in Table I. The lack of resolution occurs either because of the extremely small quadrupole interaction or because the widths of lines resulting from other interactions and instrumental limitations preclude resolution. The fact that the widths are not constant can be attributed to the rather large differences which occur in the interaction energy of the nuclear moment with the molecular rotation.

In the case of LiI , where the Li^6 line has the least width, the maxima of the intensity distribution must lie somewhere within the observed pattern. Accordingly an upper limit for the quantity $3e^2qQ_6/4h$ is 2.85 kc/sec. The quantity $e^2qQ_7/2h$ for the same molecule is 43 kc. Hence it is possible to state at once that $Q_6/Q_7 \leq 1/23 = 0.044$.

It is to be emphasized that no experimental evidence exists and that the quadrupole moment of Li^6 is other than zero. In the absence of a quadrupole moment of Li^6 , the ratio of the width of the observed line to that of the central

TABLE I. The first column lists the molecule; the second column, the frequency separation in kc/sec. between the extreme peaks of the Li^7 lines; the third column, the half-width in kc/sec. of the central component of the lines of Li^7 ; and the fourth column, the half-width of the Li^6 lines.

I	II	III	IV
LiF	102	37.0	
LiCl	48	15.5	5.5
LiBr	46	12.3	4.4
LiI	43	8.5	2.85

component of the line of Li^7 should be the ratio of the nuclear g -values. The observed ratio is about 2.85, while the ratio of the g -values is 2.64. The resolution of our apparatus is somewhat variable, depending on the velocity of the molecules in the beam. The best resolution occurs, in these experiments for LiI , where, for a perfectly homogeneous magnetic field, the resolution half-width is about 1.2 kc/sec. It is thus evident that the entire width of the observed Li^6 line can be accounted for without any broadening due to the electric quadrupole moment of Li^6 .

By use of a Hartree Model, Weisskopf² has calculated the quadrupole moment of the Li^7 nucleus to be -2.2×10^{-26} cm². Nordheim³ has proposed a model which assumes that all nuclear properties are derivable from the last odd particle in the nucleus. Mr. Vernon Hughes of this laboratory has used the model to determine the appropriate mixture of wave functions necessary to give the observed spin and magnetic moment of the nucleus. From this wave function, the quadrupole moment of the nucleus may be calculated and it is found that $Q_7 = -2.0 \times 10^{-26}$ cm². If Q_7 is taken to be -2×10^{-26} cm², then $Q_6 \leq \pm 0.88 \times 10^{-27}$ cm². The quadrupole moment of the deuteron is known⁴ to be 2.73×10^{-27} cm², and this arises because of a small admixture of a D state into the S state of the deuteron. Evidently since the quadrupole moment of Li^6 is at most one-third as great as that of H^2 , the Li^6 nucleus is in very nearly a pure S state.

I wish to acknowledge my indebtedness to Professor I. I. Rabi for his interest in the experiments and their interpretation.

¹ B. T. Feld and W. E. Lamb, Phys. Rev. **67**, 15 (1945).

² V. F. Weisskopf, private communication to I. I. Rabi.

³ L. W. Nordheim, Bull. Am. Phys. Soc., **2**, No. 1 (January 1947), and a privately circulated prepublication copy of a paper.

⁴ J. M. B. Kellogg, I. I. Rabi, N. F. Ramsey, and J. R. Zacharias, Phys. Rev. **57**, 677 (1940).

The Absorption Spectrum of Neodymium Bromate Crystals

A. BENTON AND E. L. KINSEY

University of California, Los Angeles, California
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THE visible absorption spectrum of neodymium bromate crystals with polarized light was studied by Kinsey and Krueger.¹ By the use of the theory of group representations, they obtained a quantum-mechanical explanation of the observed polarization effects and as-

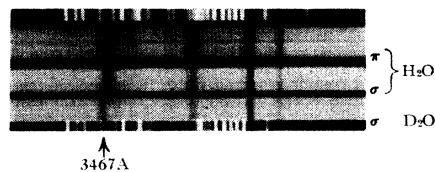


FIG. 1. The figure shows the absorption spectra of $\text{Nd}(\text{BrO}_3)_3 \cdot 9\text{H}_2\text{O}$ (labeled H_2O) and $\text{Nd}(\text{BrO}_3)_3 \cdot 9\text{D}_2\text{O}$ (labeled D_2O) taken with polarized light (π and σ denote E vector parallel and perpendicular, respectively, to the optic axis of the crystal). The $\pi\text{D}_2\text{O}$ spectrum is omitted because it bears the same relationship to the $\sigma\text{D}_2\text{O}$ spectrum as does the $\pi\text{H}_2\text{O}$ to the $\sigma\text{H}_2\text{O}$.

signed quantum numbers to many of the energy levels of the neodymium ion in the crystal. We extended their work to the ultraviolet region of the spectrum. One interesting result of this work is that spectra obtained with thin (0.32 mm) crystals of $\text{Nd}(\text{BrO}_3)_3 \cdot 9\text{H}_2\text{O}$ and $\text{Nd}(\text{BrO}_3)_3 \cdot 9\text{D}_2\text{O}$ are identical in all respects except one. The strong line which appears in the former at 3469 Å (28826 cm^{-1}) is displaced toward higher frequencies by 17 cm^{-1} in the latter, appearing at 3467 Å (28843 cm^{-1}). This shift of one and only one strong line, which occurs in both polarizations, is so remarkable that a photograph of it made on a large Littrow type Bausch and Lomb spectrograph is reproduced in this preliminary note (Fig. 1). The shift appears to be in some way connected with an interaction between electronic energy levels of the Nd^{+++} ion and those of curtailed rotations of the water molecules in the crystal lattice.

The ultraviolet absorption spectrum of neodymium bromate was found to have only one group of very strong, fairly sharp lines. The five lines of this group occur at 3562, 3552, 3538, 3509, and 3469 Å. By following an analysis similar to that employed by Kinsey and Krueger in their work on the visible spectrum of neodymium bromate, these lines were shown to be the result of electronic transitions from the $^4\text{I}_{9/2}$ ground state of Nd^{+++} to each of the five component levels into which the $^2\text{G}_{7/2}$ upper state is split by the crystal field. The analysis also furnished the M quantum numbers associated with each level.

After completion of the work in the ultraviolet, the spectra of $\text{Nd}(\text{BrO}_3)_3 \cdot 9\text{H}_2\text{O}$ and $\text{Nd}(\text{BrO}_3)_3 \cdot 9\text{D}_2\text{O}$ in the visible region were compared. No shift of any strong line of the type found in the ultraviolet was observed. Differences, however, in the two spectra appeared when very thick (4 mm) crystals were used. It was found that several very weak lines, present only with thick crystals, were displaced in the one spectrum relative to the other. A detailed analysis showed these lines to result from a coupling of the 3μ -vibrational terms of the water molecules in the crystal lattice with electronic terms of the Nd^{+++} ion.

¹ E. L. Kinsey and R. W. Krueger, Phys. Rev. **62**, 82 (1942).

On The Compressibility of Metallic Cesium

R. M. STERNHEIMER

Department of Physics, University of Chicago, Chicago, Illinois,

AND

Department of Physics, Yale University, New Haven, Connecticut*

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THE volume discontinuity of cesium¹ at $45,000 \text{ kg/cm}^2$ is too large (about 11 percent) to be accounted for by a change of crystal structure. The probable explanation is that the free electrons which normally occupy the 6s band are forced into the empty 5d band at higher pressures. A Wigner-Seitz² calculation shows that the energy *versus* volume curves for the bottom of the 5d band and the top of the 6s band cross at approximately the volume where