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# ACOUSTIC PARAMAGNETIC RESONANCE OF CHROMOUS IONS IN MAGNESIUM OXIDE UNDER APPLIED STRESS*

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Acoustic paramagnetic resonance due to $Cr^{2+}$ ions in MgO has been observed as a function of applied uniaxial stress. The measured $g$ value changes with stress. It is found that $\Delta g/\Delta e_{\Theta} = -1.05 \times 10^{4}$. This enables a value of the ion-lattice coupling coefficient to be found $a\varepsilon = 8.600D$, where $D$ is the spin-orbit parameter.

## АКУСТИЧЕСКИЙ ПАРАМАГНИТНЫЙ РЕЗОНАНС ИОНОВ ХРОМА В ОКИСИ МАГНИЯ ПОД ДЕЙСТВИЕМ ПРИЛОЖЕННОГО НАПРЯЖЕНИЯ

В работе приведены результаты исследований акустического парамагнитного резонанса в окиси магния, обусловленного ионами хрома $Cr^{2+}$, в зависимости о приложенного одноосного напряжения. Измеренное значение $g$ изменяется в зависимости от изменения напряжения. Найдено, что $\Delta g/\Delta e_{\Theta} = -1{,}05 \cdot 10^{-4}$. Это позволяет определить значение коэффициента $a_{\varepsilon}$ связи ионов в решетке. Этот коэффициент равен $a_{\varepsilon} = 8{,}600D$, где $D$ является спин-орбитальным параметром.

## I. INTRODUCTION

The chromous ions in magnesium oxide has been investigated by a variety of methods for a number of years. The ion is strongly coupled to the crystal lattice and undergoes a Jahn—Teller effect. It gives strong acoustic paramagnetic resonance [1] and strong ultrasonic relaxation absorption [2]. It produces a marked reduction in thermal conductivity [3], [4] and scatters heat pulses [5]. The theory of the chromous ion in magnesium oxide has been given by Fletcher and Stevens [6] and by Ham [7]. In spite of all this work there is still no agreement on the magnitudes of the parameters to be used in the theory. We have examined the effects of an applied uniaxial static stress on the acoustic paramagnetic resonance (apr) spectrum and have been able to obtain an estimate of the ion-lattice coupling

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constants, $a\varepsilon$, in the notation of Fletcher and Stevens [6], in terms of the spin-orbit parameter $D$.

## II. EXPERIMENTS

Samples of chromium doped MgO nominally containing 800 ppm of chromium were cut and polished to allow ultrasonic propagation along the [010] direction. Longitudinal ultrasonic waves at 9.5 GHz were generated by a quartz rod transducer in a microwave resonant cavity and by using a pulse-echo technique the ultrasonic attenuation could be measured as a function of the applied magnetic field. The experiments were made in liquid helium at a temperature of 4.2 K. A compressional stress could be applied to the sample by means of a rod down the cryostat. The stress was applied in the [100] direction while the magnetic field could be applied at directions in the (010) plane. The apr spectra were plotted for the *'as received'* crystal and when it had been heated at 1300 °C for 24 hours in oxygen to reconvert all chromium to the $Cr^{3+}$ state followed by $2\frac{1}{2}$ hours in hydrogen at 1300 °C to convert some $Cr^{3+}$ to $Cr^{2+}$. The results obtained were similar before and after heat treatment.

## III. RESULTS

Apr absorption were observed similar to those found by Marshall and Rampton [1] having tetragonal symmetry. One resonance peak followed the expression $h\nu = g_{\cdot}\beta H \cos \Phi$, where $\Phi$ is the angle between the magnetic field $H$ and the [001] direction. The value of $g_{\cdot}$ was a function of applied compression. Figure 1 shows the variation of $g_{\cdot}$ with applied strain. The strain $e_\Theta = e_{zz} - \frac{1}{2}(e_{xx} + e_{yy})$ was calculated from the applied stress and the elastic constants of MgO [8].

## IV. THEORY

The $Cr^{2+}$ ion in MgO undergoes a Jahn—Teller effect and the low-lying energy levels consist of a group of 10 states and a group of 5 states of slightly higher energy [6, 7]. The apr is due to transitions between two members of a triplet belonging to the $T_1$ representation of the cubic group. The effect of a tetragonal strain at the $Cr^{2+}$ ion site is to split this triplet into a singlet and doublet and also to admix some of the other higher lying $T_1$ and $T_2$ states into it. The admixture gives a change in the parameter $g_{\cdot}$. The change in $g_{\cdot}$ for small strains is given by:



$$g_{\cdot} = 2 - 4\sqrt{3}\left(\frac{a\varepsilon}{D}\right) e_\Theta \left\{\frac{1}{2P}\left[\frac{f_1(\delta/D - f_1 + P) + 2f_2^2}{\delta/D + 3f_1 - P} - \frac{f_1(\delta/D - f_1 - P) + 2f_2^2}{\delta/D + 3f_1 + P}\right]\right\},$$

where $P = \sqrt{(\delta/D - f_1)^2 + 4f_2^2}$ for $B > 0$ and

$$g_{\cdot} = 2(1 - 3\sin^2\beta_2) - 4\sqrt{3}\left(\frac{a\varepsilon}{D}\right) e_\Theta \left\{\frac{1}{2Q}\left[\frac{f_1(\delta/D + f_1 + Q) - 2f_2^2}{-\delta/D + 3f_1 + Q} - \frac{(\delta/D)f_2^2}{3Q^2}\right]\right\},$$

where

$$Q = \sqrt{(\delta/D + f_1)^2 + 4f_2^2} \quad \text{and} \quad \tan 2\beta_2 = 2f_2D/(\delta + f_1D) \quad \text{for} \quad B < 0.$$

In these expressions $\delta$ is the tunnelling splitting, $B$ the anharmonic coupling parameter, $f_1, f_2$ are matrix elements as defined by Fletcher and Stevens [6].

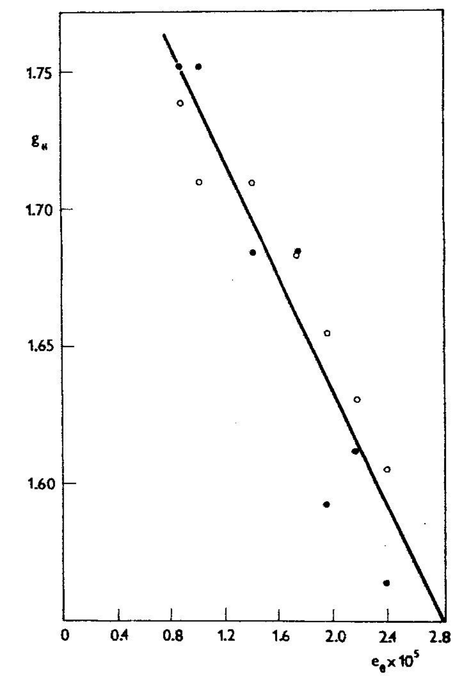


Fig. 1. Variation of $g_{\cdot}$ with strain component $e_\Theta$. Open circles $\Phi = 40°$, closed circles $\Phi = 50°$

## V. DISCUSSION

The expressions given above show $g_{\cdot}$ as a function of $a\varepsilon/D$ and of $\delta/D$. We have used the values of $f_1$ and $f_2$ given by Fletcher and Stevens [6] and computed the change in $f_{\cdot}$ for various values of $\delta/D$ in the range 2 to 100. Hence, we can find

$a\varepsilon/D$ using the results shown in Fig. 1. The slope of the best fit line shown in Fig. 1 is $\Delta g/\Delta e_{\Theta} = -1.05 \times 10^4 \pm 0.12 \times 10^4$. There are several choices available for $\delta$ and $D$. Challis et al. [3] give $\delta/D = 4$ and $D = 4\ cm^{-1}$. Using these values we obtain $a\varepsilon = 14.800\ cm^{-1}$ if $B > 0$ or $a\varepsilon = 48.000\ cm^{-1}$ if $B < 0$. Lange [2] gives $\delta/D = 8$ and $D = 2.3\ cm^{-1}$. Using these values we obtain $a\varepsilon = 10.400\ cm^{-1}$ if $B > 0$ or $a\varepsilon = 19.800\ cm^{-1}$ if $B < 0$. A value of $a\varepsilon = 17.000\ cm^{-1}$ has been found by Rivallin et al. [4]. This suggests that using the values of $\delta$ and $D$ given by Lange and the case $B < 0$ gives the best agreement with our results.


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