

sharp peaks, and from the fact that no corresponding  $K$  lines can be seen it can be concluded that the peaks are the result of  $E2$  transitions in the three abundant even- $A$  isotopes. This is also the type of transitions expected for rotational states of even- $A$  nuclei. The  $M'$  and  $M''$  lines cannot be resolved from the  $L''$  and  $L'''$  lines, respectively, although they do make these peaks somewhat broader than the  $L'$  line. The three excitation energies in question are found to be 102 kev, 113 kev, and 124 kev. As the three isotopes are about equally abundant, this is in good agreement with the average energy of 115 kev found for the gamma radiation. The 124-kev line can be assigned to the isotope  $W^{186}$ , which is known to have approximately this excitation energy for the first level. It is to be expected that the 102-kev line is the result of  $W^{182}$  and the 113-kev line to  $W^{184}$ .

We are going to check these assignments on separated targets, and we also hope thereby to find the lines for the odd isotope  $W^{183}$ , which in the present case may be covered by those of the even isotopes.

The absolute cross sections have not been determined very accurately in the present measurements, but the estimates are in agreement with our previous work.<sup>2</sup> We intend to make more careful measurements of the total Coulomb-excitation cross sections in order to get more reliable values for the quadrupole moments as well as for the magnetic moment, which can be derived from the corresponding transition probabilities.

The large broad peak at the low energies, which can be seen in Fig. 3, was also found in the case of Ta and other elements. It is believed to be the result of stopping electrons<sup>9</sup> which, by means of momentum exchange with their nuclei, have acquired more energy than the maximum of about 4 kev obtainable in a free collision with a 1.75-Mev proton. The cut-off at the low-energy side is the result of the 0.9-mg/cm<sup>2</sup> mica window of the counter. Such peaks were found to have a shape practically independent of the proton energy and the target material, but to have thick target yields which were approximately proportional to  $Z^{5/2} \cdot E^4$ . Unfortunately, this process implies that the present method also is less applicable at very low excitation energies.

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### **Zeeman Splitting of Nuclear Quadrupole Resonance Lines\***

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THE nuclear quadrupole resonance line in sodium chlorate is a narrow intense absorption line at room temperature<sup>1</sup> and is, therefore, well suited for studies of the Zeeman effect.<sup>2</sup> The crystal lattice is a simple cube in which there are four unique directions of the gradient of the electric field at the chlorine nucleus; these four directions are along the diagonals of the unit cell.

When a single crystal of sodium chlorate is placed in an external magnetic field, the zero-field nuclear quadrupole resonance line generally splits into four components. This Zeeman pattern depends upon the external magnetic-field strength and upon the orientation of the crystal with respect to the external field. At certain orientations only two or three Zeeman components are observed. These observations are readily interpreted in terms of perturbation theory.

The theory predicts that at one orientation, in which the 111

plane is normal to the magnetic field, there should be two symmetrical Zeeman components whose frequency separation from the parent line is *strictly* proportional to the strength of the applied field. In order to verify this prediction we have studied the splitting of the  $Cl^{35}$  line in external fields in the range 0 to 8000 gauss. At the highest fields employed the separation between the Zeeman components is approximately 20 percent of the frequency of the zero-field line. The experimental results show that the splitting is indeed directly proportional to the applied field.

From the observed Zeeman pattern the nuclear magnetic moment of  $Cl^{35}$  can be calculated. The value obtained is  $0.8215 \pm 0.0010$  nuclear magnetons. This result is in excellent agreement with the value  $0.82180 \pm 0.00005$  nuclear magnetons obtained in earlier work on magnetic resonance, in which aqueous solutions of LiCl were employed.<sup>3</sup> Diamagnetic corrections have not been applied in either quoted value.

Our work on sodium chlorate is being continued. Zeeman patterns for various orientations and field strengths are being investigated. Studies of line widths are also in progress. Further results will be reported in the near future.

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### **Hyperfine Structure and Nuclear Electric Quadrupole Moment of Boron 11**

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THE hyperfine structures of the  $^2P_{1/2}$  ground state and the  $^2P_{3/2}$  metastable state of boron 11 have been measured by the atomic beam magnetic resonance method. The nuclear spin of  $B^{11}$  being  $\frac{3}{2}$ , the hyperfine structure of the  $^2P_{1/2}$  state consists of two levels characterized by the total quantum numbers  $F=2$  and 1, whereas that of the  $^2P_{3/2}$  state consists of four levels characterized by  $F=3, 2, 1$ , and 0. Transitions between Zeeman components of the various levels have been observed at low magnetic fields and the field-free intervals obtained by extrapolation. We find:

$$\begin{aligned} &^2P_{3/2} \\ \Delta\nu(F=3-F=2) &= 3a' + b = 222.737 \pm 0.010 \text{ Mc/sec,} \\ \Delta\nu(F=2-F=1) &= 2a' - b = 144.00 \pm 0.02 \text{ Mc/sec,} \\ \Delta\nu(F=1-F=0) &= a' - b = 70.66 \pm 0.20 \text{ Mc/sec,} \end{aligned}$$

$$\begin{aligned} &^2P_{1/2} \\ \Delta\nu(F=2-F=1) &= 2a'' = 732.4 \pm 0.1 \text{ Mc/sec,} \end{aligned}$$

where we have expressed the intervals in terms of the theory of Casimir,<sup>1,2</sup>  $a'$ ,  $a''$  being magnetic dipole interaction constants and  $b$  an electric quadrupole interaction constant. Of the three intervals of  $^2P_{1/2}$ , the smallest one has been measured less accurately than the other two. The reason for this is that it was necessary to use a two-frequency transition, in the manner described by Davis, Feld, Zabel, and Zacharias,<sup>3</sup> in order to observe this interval and the resulting intensity was consequently lower than that in the other cases. If we solve for  $a'$  and  $b$  from the first two relations above, we obtain

$$a' = +73.347 \pm 0.006 \text{ Mc/sec, } b = +2.695 \pm 0.016 \text{ Mc/sec,}$$

where the positive sign of  $a'$  is taken from the known positive magnetic moment of  $B^{11}$ . These two values are consistent with the third relation above, for we have  $a' - b = 70.652 \pm 0.022 \text{ Mc/sec}$ . The possibility of describing the three observed intervals of  $^2P_{1/2}$  by the two constants  $a'$  and  $b$  indicates that, to within the accuracy of

the measurements, this state is unperturbed by the  $^2P_1$  ground state which lies only  $16\text{ cm}^{-1}$  away. Taking the fourth relation above into consideration, we find for the ratio of the magnetic dipole interaction constants of the  $^2P_1$  and  $^2P_3$  states  $a''/a' = 4.993 \pm 0.001$ . This ratio is to be compared with the theoretically expected one<sup>1,2</sup> of 5.0014. The good agreement between these two ratios suggests that the ground configuration which gives rise to the states under study is relatively free from the type of configuration interaction considered by Koster.<sup>3</sup> Hence, a nuclear quadrupole moment calculated from the observed constant  $b$  by the method described by Davis, Feld, Zabel, and Zacharias<sup>2</sup> should be fairly reliable. We find by this method

$$Q(B^{11}) = +(0.0355 \pm 0.0002) \times 10^{-24} \text{ cm}^2.$$

For this same quantity, Gordy, Ring, and Burg<sup>4</sup> obtained from microwave absorption spectra a value  $+(0.03) \times 10^{-24} \text{ cm}^2$  whereas Dehmelt<sup>5</sup> obtained from pure quadrupole spectra a value  $+(0.047) \times 10^{-24} \text{ cm}^2$  (without Sternheimer correction). These values are probably less reliable than ours because of the more complicated molecular fields involved. Dehmelt also obtained an accurate value for the ratio of the quadrupole moments of  $B^{10}$  and  $B^{11}$ . Using his ratio of  $Q(B^{10})/Q(B^{11}) = 2.084 \pm 0.002$  and our value of  $Q(B^{11})$ , we find  $Q(B^{10}) = +(0.0740 \pm 0.0005) \times 10^{-24} \text{ cm}^2$ .

The apparatus used in the present study has been described by Wessel and Lew.<sup>6</sup> An attempt will be made to measure the hyperfine structure of  $B^{10}$ .

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## A New Quenching Effect in Liquid Scintillators

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LIQUID scintillator studies, initiated in connection with a C<sup>14</sup> liquid-scintillator dating project, have revealed the existence of a considerable quenching effect attributable to dissolved oxygen, an effect which does not appear to have been recognized by other workers in this field. The precise nature of the quenching process is obscure, but it seems likely that photo-oxidation and photo-dimerization are involved, and each may act to reduce substantially the light output of the scintillator. In the former case a process competing with the light-emission mechanism is involved, and in the latter case the effective number of activator molecules is reduced. It must be noted that pioneer studies of fluorescence quenching had revealed effects caused by oxygen which were described in 1938.<sup>1</sup>

The displacement of the dissolved oxygen from the liquids was accomplished by bubbling nitrogen through a fine capillary tube sealed into the glass scintillation cell. The nitrogen was first passed through magnesium perchlorate and pyrogallol. The scintillation cell had a diffuse reflecting coating of magnesium oxide on the outside, and the light output was measured in terms of the pulse heights from a DuMont 6292 photomultiplier. The light output of an anthracene crystal, similarly mounted, was used for reference, and the scintillations were produced by gamma rays from a Cs<sup>137</sup> source. It was found that nitrogen bubbling improved the pulse height in every case and that the effect could be reversed by bubbling with oxygen. A heated tube containing finely divided copper was inserted in the bubbling line to remove the last traces of oxygen but did not noticeably improve the performance.

Figure 1 illustrates the nature of the improvement for xylene solutions of 3-g/l *p*-terphenyl with varying concentrations of diphenyloxazole. It will be observed that the removal of oxygen doubles the light output of the pure *p*-terphenyl-xylene solution.

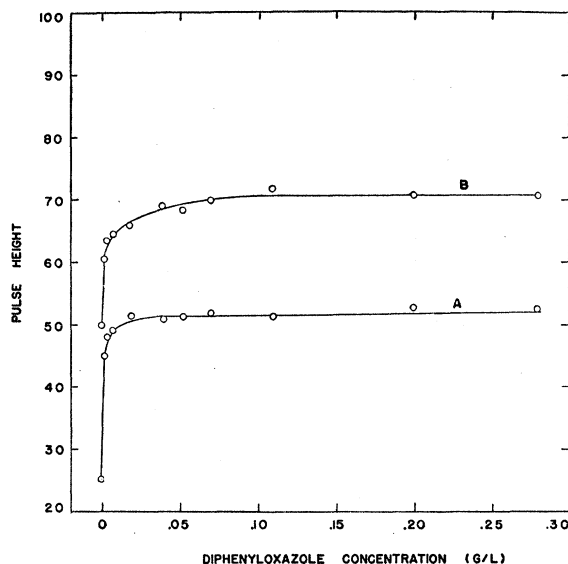


FIG. 1. Scintillation pulse height (relative to anthracene as 100) vs diphenyloxazole concentration for a 3-g/l terphenyl-xylene solution. Curve A: unbubbled solution. Curve B: bubbled solution.

The effect of the addition of diphenyloxazole is also most interesting, as one part in  $10^6$  added to the solution causes considerable enhancement of the light emission. Figure 2 illustrates a similar improvement for *p*-xylene, showing the effect of adding *p*-terphenyl to solutions with a fixed concentration of diphenyloxazole. Table I also indicates a few representative results.

It should be noted that the photomultiplier used in these experiments did not have an extended sensitivity in the ultraviolet, and so the light emission of the liquids is not measured under circumstances as favorable as for the anthracene, since the emission curve in the latter case corresponds more closely with the sensitivity curve of the photocathode. It is estimated that an ultraviolet-sensitive photomultiplier would so increase the relative light outputs of the liquids, that the best bubbled solutions would appear superior to anthracene.

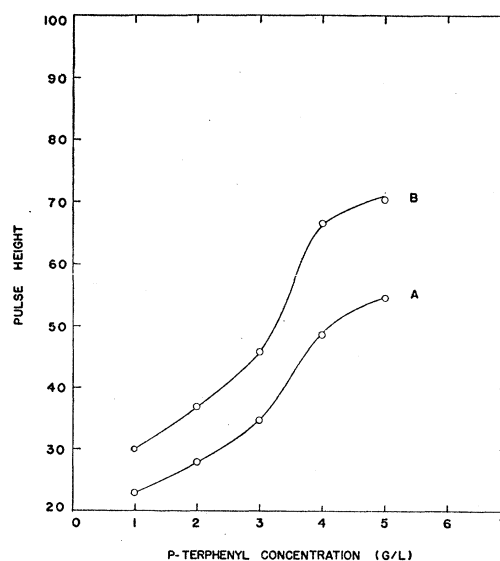


FIG. 2. Scintillation pulse height (relative to anthracene as 100) vs *p*-terphenyl concentration for a 0.1-g/l diphenyloxazole-*p*-xylene solution. Curve A: unbubbled solution. Curve B: bubbled solution.