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# The Nuclear Spin and Magnetic Moment of $Li^6$

J. H. MANLEY AND S. MILLMAN,* *Columbia University, New York, N. Y.*

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The spin of the $Li^6$ nucleus and the h.f.s. separation of the ${}^2S_{\frac{1}{2}}$ normal state have been measured by the atomic beam method of zero moments. The evaluation of the contribution of $Li^7$ to the intensity in the neighborhood of the $Li^6$ zero moment peak was made by an extension of the method of analysis previously used in determining the spin of $K^{41}$ and $Rb^{87}$. The spin of $Li^6$ was found to be 2/2 and the h.f.s. separation $0.0077 \pm 0.0001$ cm$^{-1}$ on the basis of the value of Fox and Rabi for $Li^7$. The ratio of the magnetic moments of the isotopes is $\mu_6/\mu_7 = 0.258 \pm 0.5$ percent. From the value calculated by Breit and Doerman for $Li^7$, the moment of $Li^6$ is 0.85 nuclear magneton.

## INTRODUCTION

APPROXIMATE determination of the magnetic moment of the $Li^6$ nucleus has been made by Schüler[1] from hyperfine structure measurements and an assumption of the nuclear spin. The resolution was insufficient for an accurate determination of the separation and completely inadequate for a determination of the spin. The measurements of Fox and Rabi[2] on $Li^7$ by the atomic beam method indicated that this method could also be used for the less abundant isotope. They were able to conclude that the spin of $Li^6$ is 2/2 or greater and that the moment ratio $\mu_6/\mu_7$ lies between 0.15 and 0.25. The results of the measurements described in this paper have been previously summarized.[3]

## APPARATUS AND PROCEDURE

With a few modifications the apparatus was that used in the investigation of $K^{41}$.[4] The resolution was increased by reducing the height of the beam to 1.5 mm which gave a variation of the field over this height of less than two percent. Further resolution was obtained by the insertion of a slit 0.01 mm wide before a four-mil tungsten detecting filament. This arrangement eliminated the fragileness of small diameter filaments necessary to secure comparable resolution. For good detection of lithium it was found convenient to supply a continuous oxygen flow to the surface of the filament. A small jet directed at the filament and connected through a capillary with an oxygen reservoir maintained the necessary high work-function surface at all times.

As in all measurements by this method, the beam intensity at the undeflected position is obtained as a function of the current which produces the inhomogeneous magnetic field. Sufficient intensity for accurate measurements was obtained with an oven temperature of about 750°C.

## RESULTS

A typical curve showing the variation of beam intensity with field current is given in Fig. 1. The zero moment peak due to $Li^6$ occurs at about 22 amperes, that due to $Li^7$ near 116 amperes. The intensity in the 40−105 ampere region is constant, and therefore this portion of the curve has been omitted. The insert, *A*, of Fig. 1 is a portion

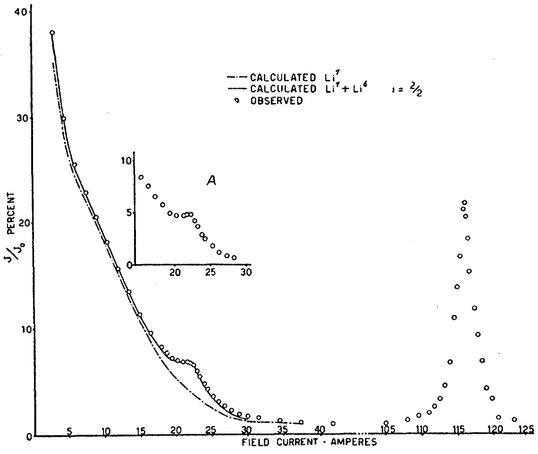

FIG. 1. A typical curve of the beam intensity at the undeflected position as a function of the current producing the magnetic field. The insert, *A*, is a portion of a similar curve taken with slightly higher resolution.

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* Barnard Fellow.

[1] Schüler, Zeits. f. Physik **99**, 285 (1935); **66**, 431 (1930).

[2] Fox and Rabi, Phys. Rev. **48**, 746 (1935).

[3] Manley and Millman, Phys. Rev. **50**, 380 (1936).

[4] Manley, Phys. Rev. **49**, 921 (1936).

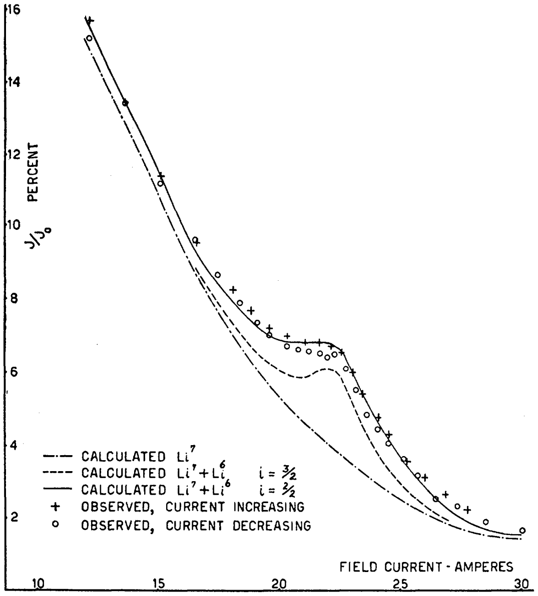

FIG. 2. The $Li^6$ peak region of Fig. 1 plotted to a larger scale to show the calculated curves for spins of 2/2 and 3/2.

of a curve taken with higher resolution but at some sacrifice of accuracy of intensity measurements. The spin calculations are therefore based on results with less than the maximum possible resolution.

For an unambiguous determination of the spin of $Li^6$ it is essential to evaluate the $Li^7$ background in the 22 ampere region. The necessary data for this calculation is furnished by the course of the curve in the neighborhood of the $Li^7$ zero moment peak. This calculation can be carried out by an extension of the method already applied in the determination of the nuclear spin of $K^{41}$ and $Rb^{87}$.[5]

For the purposes of these deflection experiments the property which distinguishes the atoms of one isotope from those of another, or atoms of different magnetic quantum states of either isotope, is the effective magnetic moment of the atom. Since the force on an atom in an inhomogeneous magnetic field of the type used is proportional to the product of the magnetic moment of the atom and the current in the field, the fraction of atoms of a given magnetic state remaining at the position of zero deflection depends on this product. All other quantities such as beam shape, energy-distribution, etc., which enter an intensity expression are common to atoms of any state of either isotope. Hence a knowledge of the variation of intensity with respect to this moment-current product for any one state of either isotope permits the evaluation of the contribution of any other state to the total intensity at any current, provided the nuclear spin is known. The proviso is necessary because of the dependence of the atomic moment on the spin of the nucleus. In the region of the $Li^7$ zero moment peak the intensity is due solely to atoms of the $m=-1$ states of $Li^7$. Since the nuclear spin of this atom is known, the moment may be calculated for any value of the field current from the Breit-Rabi formula.[6] The observed intensity due to these states plotted as a function of the moment-current product yields the desired calibration curve. At any current the moment-current product for each magnetic state of $Li^7$ is then calculated and the corresponding intensity read from the calibration curve. The sum of these intensities is the total contribution of $Li^7$ to the intensity at the current chosen. The result of this procedure is shown in the dot-dash curve of Fig. 1 and Fig. 2.

In a similar manner, the same calibration curve can be used to calculate the contribution of $Li^6$ to the intensity at any current. A spin is assumed, the moment-current product calculated, and the intensity contribution read from the curve. The reading gives the fraction of atoms of any state which remain at the position of zero deflection. The absolute intensity is obtained by using the mass-spectrographic abundance ratio 11.6.[7] The total intensity of all states of $Li^6$ is then added to the calculated $Li^7$ background. The solid curve of Figs. 1 and 2 is the result for an assumed spin of 2/2 for $Li^6$, and the dotted curve of Fig. 2 for a spin of 3/2. The two sets of experimental points are in good agreement with the 2/2 curve but deviate considerably from the curve for 3/2 in the region of the $Li^6$ peak where the comparison is particularly significant. The departure from the 2/2 curve occurs at the values of the moment-current product for which the calibration curve is less accurate.

A careful search was made to determine the

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[5] Millman and Fox, Phys. Rev. **50**, 220 (1936).

[6] Breit and Rabi, Phys. Rev. **38**, 2082 (1931).

[7] Brewer, Phys. Rev. **49**, 635 (1936).

possible presence of additional zero moment peaks. It is certain that none exist at currents greater than 22 amperes. While no peaks or breaks in the curve were found at currents less than this value, there is a slight possibility that the large $Li^7$ intensity would mask their presence. However, if the spin is greater than 3/2 the peak which is evident would have to be the high-current peak. For such cases this peak can be calculated by the method described and would lie between the 3/2 curve and the $Li^7$ background in the 22 ampere region (Fig. 2). It would therefore deviate more markedly from the observed points than the curve obtained for an assumed spin of 3/2. It is concluded from this analysis that the spin of the $Li^6$ nucleus is 2/2.

The ratio of the h.f.s. separations of the two isotopes follows from the ratio of the currents at the zero moment peaks. Several determinations of this ratio have been made under various conditions with the result,

$$I_p(\mathrm{Li}^6)/I_p(\mathrm{Li}^7)=0.193\pm 0.5 \text{ percent},$$
$$\Delta\nu(\mathrm{Li}^6)/\Delta\nu(\mathrm{Li}^7)=0.290\pm 0.5 \text{ percent}.$$

This ratio and the value 0.0267 $\mathrm{cm}^{-1}$ for $\Delta\nu(\mathrm{Li}^7)$ from the results of Fox and Rabi[2] yield

$$\Delta\nu(\mathrm{Li}^6)=0.0077\pm 0.0001\ \mathrm{cm}^{-1}.$$

The ratio of the nuclear magnetic moments is given by

$$\mu_6/\mu_7=[\Delta\nu(\mathrm{Li}^6)/\Delta\nu(\mathrm{Li}^7)]$$
$$[\{2i/2i+1\}_6/\{2i/2i+1\}_7]=0.258\pm 0.5 \text{ percent}.$$

On the basis of the value 3.28 calculated by Breit and Doerman,[8] the nuclear moment of $Li^6$ is 0.85 nuclear magneton.

## CONCLUSION

$Li^6$ is one of the small group of four nuclei (D, $Li^6$, $B^{10}$, $N^{14}$) of odd atomic number which are composed of equal numbers of protons and neutrons. Three of these (D, $Li^6$, $N^{14}$) are now known to have a spin 1. The nuclear moment of the deuteron as measured by Kellogg, Rabi and Zacharias[9] and that of $Li^6$ are the same. This equality lends support to the argument of Bethe and Bacher[10] that the normal state of the $Li^6$ nucleus, like that of D, is $^3S_1$. If perturbations due to other nuclear configurations are of minor importance in their effect on the $Li^6$ moment, one may now say that the intrinsic moments of the proton and neutron are the same in the two nuclei to within the experimental error of a few percent.

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[8] Breit and Doerman, Phys. Rev. **36**, 1262 (1930).

[9] Kellogg, Rabi, Zacharias, Phys. Rev. **50**, 472 (1936).

[10] Bethe and Bacher, Rev. Mod. Phys. **8**, 182 (1936).