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# The Nuclear Mechanical Moment of Lanthanum from Hyperfine Structure

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The hyperfine structure of the lines λλ5212, 5234 and 6250 of $La_I$ has been observed with a flint glass spectrograph crossed with Fabry-Perot etalons. A liquid-air cooled Schüler tube was used as a source. The number of components, the intensity ratios and the interval spacing are all in good agreement with the value $I=(7/2)(h/2\pi)$ for the nuclear mechanical moment.

## INTRODUCTION

FROM preliminary results on the hyperfine structure in both the arc and the spark spectra of lanthanum by Meggers and Burns,[1] White[2] has suggested that the nuclear mechanical moment is probably $(5/2)(h/2\pi)$. The object of this investigation is a more careful determination of this value with instruments of higher resolving power.

A one-meter flint glass spectrograph crossed with Fabry-Perot interferometers was used to photograph the spectrum. The source was a liquid-air cooled Schüler tube operating on 2000 volts with currents ranging from 0.15 to 0.35 ampere. Small pieces of lanthanum metal were placed in the hollow steel cathode and argon at a few mm pressure was circulated through the system. Densitometer traces of the etalon patterns and of the calibration marks used for the intensity measurements were taken on a Zeiss recording microphotometer.

## EXPERIMENTAL PROCEDURE

Exposure times varied from five to thirty minutes. The spectra were photographed on Eastman Panchromatic plates which were developed in 1 : 20 Rodinal at 18°C. In this way very clear plates were obtained and the Eberhard effect reduced to a minimum.

Intensity calibration spectra were photographed on each plate so that exactly the same treatment in developing and fixing would be given the calibration spectra and the spectrum under investigation. These calibration marks were photographed by removing the etalons from their position between the collimating lens and the prisms, and by using a calibrated step-slit,[3] with 7 apertures varying in width between 0.01 cm and 0.12 cm. The step-slit was evenly illuminated by placing a 6 volt tungsten filament lamp some distance away on the axis of the collimator, without a condensing lens. These exposure times never differed by more than a factor of five from those of the spectrum under investigation. This ratio of exposure times is well within the limits allowed for the final accuracy claimed herein according to the work of Ornstein, Moll and Burger,[4] since it is only desired that the calibration curve shall maintain the same *shape* within this range.

For each line and each plate a calibration curve, $i/i_0$ *vs.* log $I$, was plotted, $i_0$ being the deflection for clear plate, and $i$ that for the density mark. From this curve, the peak densitometer readings were converted to relative intensities. The background on the etalon spectrum was negligible. In this way the average of the relative intensities from several determinations should not be in error by more than two percent.

## EXPERIMENTAL RESULTS

In this investigation three relatively independent methods have been employed in arriving at a value for the nuclear spin of lanthanum.

[1] W. F. Meggers and K. Burns, J. O. S. A. and R. S. I, **14**, 449 (1927).

[2] H. E. White, Phys. Rev. **34**, 1404 (1929).

[3] A. Elliott, Diss. Utrecht (1930).

[4] L. S. Ornstein, W. J. H. Moll and H. C. Burger. Objektive Spektralphotometrie, p. 51 (1932).

These are (1), a determination of the maximum number of components in a line involving large $J$ values, (2), a determination of the relative intensities of the components in a given line, and (3), a check by the Landé interval rule as it applies to the relative separations of the hyperfine levels.

In order to obtain a value from the number of components, several transitions into the widely split $5d^26s$, $^4F_{9/2}$ level have been investigated, chiefly λ6250, $^4F_{9/2}-^4G_{11/2}°$; λ5234, $^4F_{9/2}-1_{7/2}°$; and λ5212, $^4F_{9/2}-^4D_{7/2}°$. In these three patterns, the overall separations of the components are slightly different, indicating that at least two and probably all three of the upper levels have small splittings. This is just what is to be expected from the two upper levels $^4G_{11/2}°$ and $^4D_{7/2}°$, since they arise from the configuration $5d^26p$.

On several plates, with various etalon spacers, at least six components have been clearly resolved in all three of these lines, and a tailing off in each which would indicate at least one more component and probably two. As an example, the line λ6250 and the corresponding microphotometer curve are reproduced in Fig. 1. It is doubtful whether, even with a greater resolving power, the tail would be completely resolved due to the overlapping of the off-diagonal components. Thus the number of components, which is definitely at least seven and almost certainly eight, indicates that the spin is 7/2.

As the second independent determination of the nuclear moment, the relative intensities of the components of these same transitions have been measured. Due to the richness of the lanthanum spectrum, the overlapping of the line patterns has made it extremely difficult to separate the two lines λ5212 and λ5234, from their neighboring lines. By using a sufficiently narrow slit, however, densitometer traces were obtained for these two as well as for λ6250. In recording the microphotometer curve for λ6250, care was taken that a weaker overlapping line, which perhaps can be seen in Fig. 1, was not included. From readings on the densitometer trace of the calibration spectra (not shown) the calibration curve in Fig. 2 was plotted for this wave-length.

These peak intensities were then plotted as in Fig. 3 against the order $n$, measured from the center of the pattern. This was done so that a correction could be obtained for the change in intensity with order. This also automatically corrected for possible variations of intensity over the length of the slit. Thus, if corrections were made for the overlapping of the components, Fig. 3 would give the exact relative intensities of the components by reading the values of the ordinates for any one value of $n$. Furthermore, this would be expected to be constant for all values of the abscissae.

However, this correction for the overlapping of the components was not attempted since the probable presence of weak off-diagonal components would render the proper analysis of the intensity curves very uncertain. Nevertheless the densitometer trace in Fig. 1 shows that any such correction, if made, would only tend to decrease the relative intensities of the weaker components.

λ6250 Lanthanum

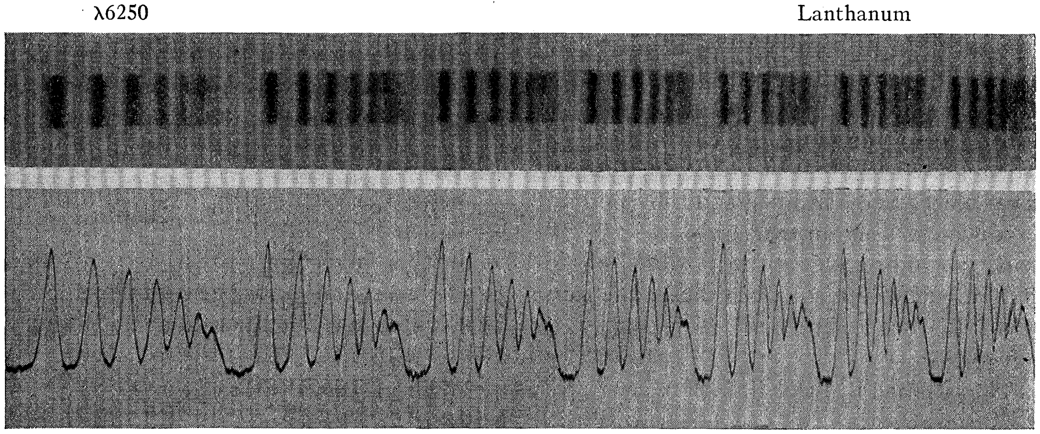

FIG. 1. Fabry-Perot etalon pattern and densitometer curve for λ6250.

Without making such a correction therefore, an upper limit for the relative intensities, and hence of the $I$ value, can be obtained and the actual value should be indicated by the intensities of the first four components, which do not show appreciable overlapping.

Fig. 4 shows four sets of ratios taken from Fig. 3 at $n=2$, 3, 4 and 5. The peak intensities, of the first five components of λ6250, thus corrected only for variation with order, have been plotted against the ordinal number $m$ of the component in the pattern. The theoretical slopes for $I=5/2$, $7/2$ and $9/2$ are also given. Where the overlapping becomes great, a value of $I$ as high as $9/2$ is obtained as shown in the figure for the fourth and fifth components. Nevertheless, from the values of the ratios of the first three components, the intensity measurements fix, with a fair degree of certainty, an upper limit of $7/2$. This has been checked on several plates and with various separators.

Finally the interval rule affords the third independent determination of $I$. After correcting for the dispersion of the etalon pattern, the interval ratios of the first seven components are in good agreement with the value of $I=7/2$ deduced above. This is shown in Table I, where the theoretical ratios for $I=5/2$, $7/2$ and $9/2$ are compared with the experimental values, in which the first interval is given the value 100. The data in this table were taken from the microphotometer trace in Fig. 1, which was carefully measured on a travelling microscope. In doing this an average was taken for as many orders as possible, the first five ratios from seven and the last one from four orders. Several other plates, taken with different etalon spacers, show equally good agreement.

In the last two determinations of the nuclear mechanical moment, the possibility of an integral

TABLE I. *Theoretical and observed values of interval ratio.*

| Theoretical ratios for $I=5/2$ | 7/2 | 9/2 | Observed ratios |
|---|---|---|---|
| 100 | 100 | 100 | 100 |
| 85.7 | 87.5 | 88.9 | 86.8±1.3 |
| 71.4 | 75.0 | 77.8 | 74.4±1.4 |
| 57.1 | 62.5 | 66.7 | 61.2±1.7 |
| 42.9 | 50.0 | 55.6 | 51.7±1.8 |
| — | 37.5 | 44.4 | 38.5±2.1 |

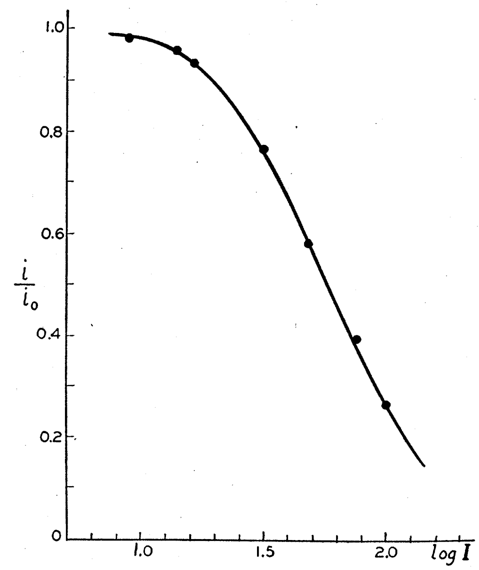


FIG. 2. Intensity calibration curve for λ6250.

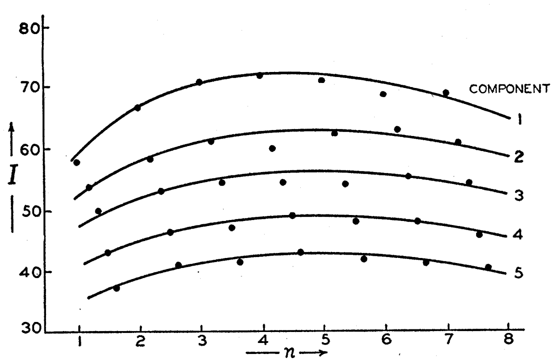


FIG. 3. Correction curves, relative intensity $I$ *versus* the order $n$.

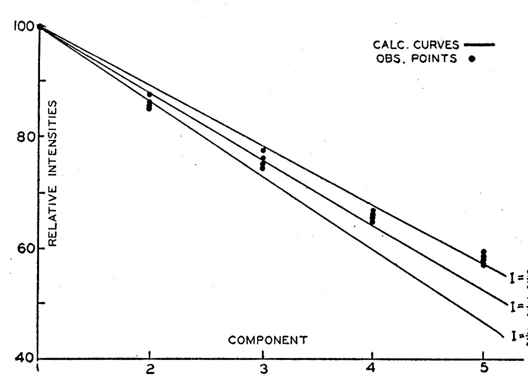


FIG. 4. Relative intensity $I$ *versus* ordinal number $m$ of component.

value has not been considered, since this is not expected for lanthanum, with an odd atomic mass number. Furthermore the accuracy of these last two determinations did not permit a distinction between two values as nearly equal as 7/2 and 6/2. However, the first determination by the number of components indicated the half integral value, 7/2.

These results may be summarized as follows, (1) the number of hyperfine components in three transitions indicate a nuclear spin of 7/2; (2) intensity measurements set, with a fair degree of accuracy, 7/2 as an upper limit; and (3) the Landé interval rule checks this same value.

In concluding, I wish to thank Professor H. E. White for suggesting the problem and for the many helpful suggestions that he has given in connection with the work. Also, I wish to thank Professor F. A. Jenkins for many useful suggestions pertaining to the intensity work; and finally Dr. F. Sanders and Dr. N. S. Grace for their help in the problem.

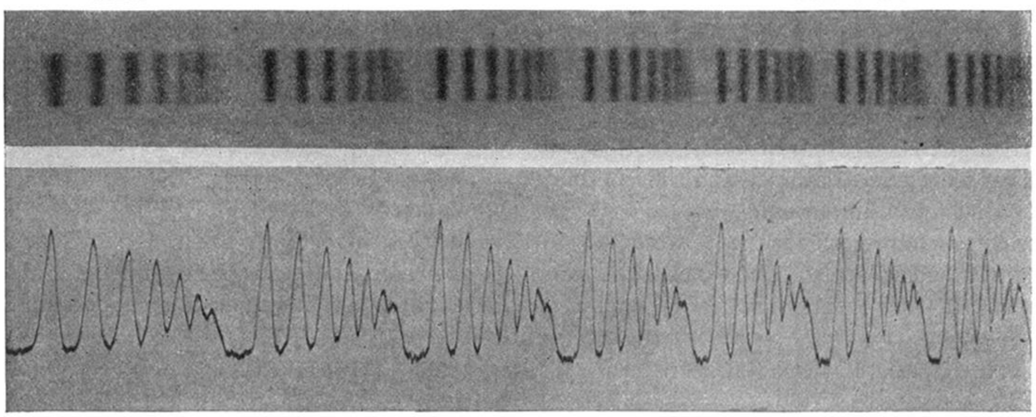


FIG. 1. Fabry-Perot etalon pattern and densitometer curve for λ6250.