AUGUST 15, 1939 PHYSICAL REVIEW VOLUME 56

Nuclear Spin and Magnetic Moment of $_{13}Al^{27}$*

S. MILLMAN AND P. KUSCH
Columbia University, New York, New York
(Received June 19, 1939)

The molecular beam magnetic resonance method has been applied to a determination of the gyromagnetic properties of the Al^{27} nucleus. The observed gyromagnetic ratio is 1.451 ± 0.004 in units of $e/2Mc$. A comparison of this ratio with that obtained from the hyperfine splitting of several aluminum lines for various assumed values of the spin of Al^{27} fixes the spin of this nucleus as 5/2. The value of the magnetic moment is then found to be 3.628 ± 0.010 nuclear magnetons. The sign of the moment is experimentally determined to be positive.

THE h.f.s. of aluminum has been the subject of several investigations which lead to discordant values for the nuclear spin of Al^{27} but yield values for the nuclear magnetic moment which are in agreement within the capabilities of the Goudsmit, Fermi-Segrè (G. F. S.) formula. Jackson and Kuhn[1] have investigated the h.f.s. of the resonance lines of Al I in absorption. From measurements of the relative intensities of the two resolved components of the line $3^2P_{1/2}-3^2D_{3/2}$ they conclude that the spin of Al^{27} is 9/2. From an analysis of the three resolved h.f.s. components of the $3^2P_{1/2}-4^2S_{1/2}$ line the same investigators obtain the hyperfine splitting of the $3^2P_{1/2}$ and $4^2S_{1/2}$ states. For an assumed spin of 9/2 the Goudsmit formula yields 3.6 and 4.1 nuclear magnetons as the magnetic moment of Al^{27}, when applied to the two observed splittings, respectively. Heyden and Ritschl[2] have observed the h.f.s. of several lines of Al II and by use of the interval rule find the spin of Al^{27} to be 5/2. Their data also furnish a measure of the h.f.s. of the $3s\ ^2S_{1/2}$ state of Al III from which they deduce a moment of 3.7 nuclear magnetons by use of the Fermi-Segrè formula.

We have applied the molecular beam magnetic resonance method[3] to a study of the nuclear gyromagnetic properties of Al^{27}. In order to obtain a molecular beam containing aluminum and detectable by the surface ionization method it is necessary that the molecule issuing from the oven contain an alkali atom as well as aluminum. The double salts $NaCl \cdot AlCl_3$ and $KCl \cdot AlCl_3$ were found to be suitable for our purposes. At temperatures of about 600°K these molecules show practically no dissociation and have vapor pressures sufficiently high to give workable beams.

Following the procedure discussed in earlier papers[3] three resonance curves were observed common to the two compounds used. Two of the curves are due to Cl^{35} and Cl^{37}, whose nuclear g's have already been reported[4] and are the same as those observed in such simple compounds as LiCl and RbCl. Since aluminum is the only other common constituent of the two molecules investigated and since the observed effect is much too large to be attributed to any impurities in the compounds used, the third resonance minimum must be attributed to the Al^{27} nucleus. A typical aluminum resonance curve is shown in Fig. 1. The nuclear g value, obtained from the ratio of the oscillating frequency to the magnetic field at resonance, is 1.451 ± 0.004 in units of $e/2Mc$, when referred to the nuclear g of Li^7 as standard.[3]

In order to obtain the nuclear magnetic moment from the observed g value it is necessary to know the nuclear spin. Our method does not measure spin directly. However, in cases where the total hyperfine splitting of an atomic energy state is known our independent g measurements may serve as a deciding factor in fixing the nuclear spin.

When a nuclear moment is calculated by means of the G. F. S. formula from the experimentally determined splitting of an atomic energy state the result is not particularly sensitive to the

* Publication assisted by the Ernest Kempton Adams Fund for Physical Research of Columbia University.

[1] D. A. Jackson and H. Kuhn, Proc. Roy. Soc. **A164**, 48 (1938).

[2] M. Heyden and R. Ritschl, Zeits. f. Physik **108**, 739 (1938).

[3] I. I. Rabi, S. Millman, P. Kusch and J. R. Zacharias, Phys. Rev. **55**, 526 (1939).

[4] P. Kusch and S. Millman, Phys. Rev. **55**, 680 (1939).

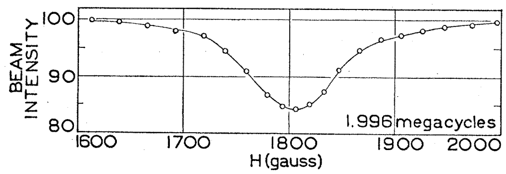

FIG. 1. Resonance curve of Al^{27} observed in $KCl\cdot AlCl_3$ with a current of 13 amp. in the wires producing the oscillating field.

assumed value of the nuclear spin, since the moment is proportional to $i/(i+\frac{1}{2})$. The gyromagnetic ratio, on the other hand, is proportional to $1/(i+\frac{1}{2})$ and is quite sensitive to the assumed value of the spin. Hence a comparison of this ratio, calculated from an observed hyperfine splitting of an energy level for various assumed values of i, with that independently measured furnishes a criterion for fixing the nuclear spin. For this it is necessary to assume only the approximate validity of the G. F. S. formula. Nuclear g calculations[5] for cases similar to those under consideration, the $^2S_{1/2}$ state of the alkalis and the $^2P_{1/2}$ state of indium, have not differed from the g values measured directly by more than ten percent.

Table I lists the observed hyperfine splitting, the quantity $(i+\frac{1}{2})g$ calculated by means of the G. F. S. formula and the resulting g values for various assumed values of the nuclear spin. Our observed g value of 1.451 agrees best in each of the three cases with that obtained by assuming a spin of 5/2. It is noteworthy that in the last two cases, where the agreement for an assumed spin of 5/2 is particularly good, the calculations are based on the h.f.s. of S states. In the first case the nuclear g is calculated from the h.f.s. of a P state. Goudsmit[6] states that it is to be expected that g values calculated from the h.f.s. of a P state will be somewhat low.

TABLE I. *Nuclear g values calculated from the h.f.s. of* Al^{27} *by use of the G.F.S. formula. The hyperfine splittings in columns 2 and 3 are those observed by Jackson and Kuhn*[1] *and that in column 4 is based on the work of Heyden and Ritschl.*[2]

STATE	$3s^23p\ ^2P_{\frac{1}{2}}$	$3s^24s\ ^2S_{\frac{1}{2}}$	$3s\ ^2S_{\frac{1}{2}}$
$\Delta\nu$ (cm^{-1})	0.048	0.048	0.516
$(i+\frac{1}{2})g$	3.90	4.48	4.41
g for $i=3/2$	1.95	2.22	2.20
$i=5/2$	1.30	1.48	1.47
$i=7/2$	0.98	1.11	1.10
$i=9/2$	0.78	0.89	0.88

The nuclear spin is thus found to be 5/2, in agreement with the result of Heyden and Ritschl. The magnetic moment, μ, is the product of the spin and the observed g and has the value 3.628 ± 0.010 nuclear magnetons. The sign of the moment is found to be positive by a method previously described.[7]

This research has been aided by a grant from the Research Corporation.

[5] P. Kusch, S. Millman and I. I. Rabi, Phys. Rev. **55**, 1176 (1939); S. Millman, I. I. Rabi and J. R. Zacharias, Phys. Rev. **53**, 484 (1938).

[6] S. Goudsmit, Phys. Rev. **43**, 636 (1933).

[7] S. Millman, Phys. Rev. **55**, 628 (1939).