On the Nuclear Spins and Magnetic Moments of the Principal Isotopes of Potassium[1]

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The spin of the K^{39} nucleus and the hfs separation of the $^2S_{\frac{1}{2}}$ normal state were measured by the deflection of a beam of neutral atoms in a weak inhomogeneous magnetic field, produced by a system of parallel wires carrying current. To attain the required resolution narrow beams and long beam paths (141 cm) were used. The nuclear spin of K^{39} was found to be 3/2. The hfs separation, $\Delta\nu$, of the normal state was measured by the method of "zero moments," which utilizes the fact that the magnetic moment of the atoms in some of the magnetic levels vanishes at certain values of the magnetic field. A plot of the variation of intensity at the center of the pattern with respect to field yields distinct maxima at these fields. If the magnetic field is known the hfs separation can be deduced with accuracy. The value of $\Delta\nu$ was found to be 0.0152 ± 0.0006 cm^{-1}. Using the modified Goudsmit formula, one obtains the value of 0.39 for the nuclear magnetic moment (in units of $\mu_0/1838$). The resolution was sufficient to resolve a "peak" due to K^{41} by the method of "zero moments." The nuclear spin was found to be greater than 1/2, and the ratio of the magnetic moments μ_{41}/μ_{39} was found to be between the limits of 0.42 and 0.88 depending on the spin of K^{41}.

INTRODUCTION

THE two isotopes of potassium, K^{39} and K^{41}, have very small nuclear magnetic moments. For this reason spectral methods[2] used up to the present have failed to determine the spins of these nuclei. Until recently nothing was known of the hyperfine structure separation of the normal $^2S_{\frac{1}{2}}$ state of K^{39} other than the fact that it was small, with $\Delta\nu$ less than 0.02 cm^{-1}. However, the measurements of Loomis and Wood[3] on the alternating intensities of the band spectra of the K_2 molecule showed that the K^{39} nucleus must possess a spin other than zero. Concerning the corresponding properties of K^{41} no information was available. The present investigation had for its object the application of the methods of molecular beams to determine the nuclear spin of K^{39}, to measure the hyperfine separation of the normal state of K^{39} and to obtain information about the corresponding properties of K^{41}. These methods have already been applied with decisive results to determine the nuclear spins of sodium[4] and caesium.[5]

METHOD

The experimental method utilizes the fact that an alkali atom in the normal $^2S_{\frac{1}{2}}$ state and possessing nuclear spin i has some magnetic levels in which the moment of the atom becomes zero at definite values of the magnetic field. In such fields these atoms are not deflected in an inhomogeneous field. From the number of such levels and the values of the field at which they possess this property we can obtain both the spin of the nucleus and the hyperfine structure separation $\Delta\nu$ of the normal state.

The force on an atom in the normal $^2S_{\frac{1}{2}}$ state possessing nuclear angular momentum i, in units of $h/2\pi$, situated in an inhomogeneous magnetic field is given by.[6]

$$F_y=\pm\frac{2m/(2i+1)+x}{[1+(4m/(2i+1))x+x^2]^{\frac{1}{2}}}\mu_0\frac{\partial H}{\partial y}=f_m\mu_0\frac{\partial H}{\partial y}, \quad (1)$$

$$x=2\mu_0H/hc\Delta\nu. \quad (2)$$

$\Delta\nu$ is the energy difference in wave numbers between the two states with total angular momentum $F=i+\frac{1}{2}$ and $F=i-\frac{1}{2}$, m is the total magnetic quantum number, the projection of F along H, and f_m is the effective magnetic moment

[1] A preliminary report on the spin and magnetic moment of K^{39} was submitted earlier. Millman, Fox and Rabi, Phys. Rev. **46**, 320 (1934).

[2] Schuler and Bruck, Zeits. f. Physik **58**, 735 (1929); Frisch, Physik. Zeits. Sowjetunion **1**, 302 (1932); Frisch, Physik. Zeits. Sowjetunion **4**, 557 (1933).

[3] Loomis and Wood, Phys. Rev. **38**, 854 (1931); Loomis, Phys. Rev. **38**, 2153 (1931).

[4] Rabi and Cohen, Phys. Rev. **46**, 707 (1934).

[5] Cohen, Phys. Rev. **46**, 713 (1934).

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

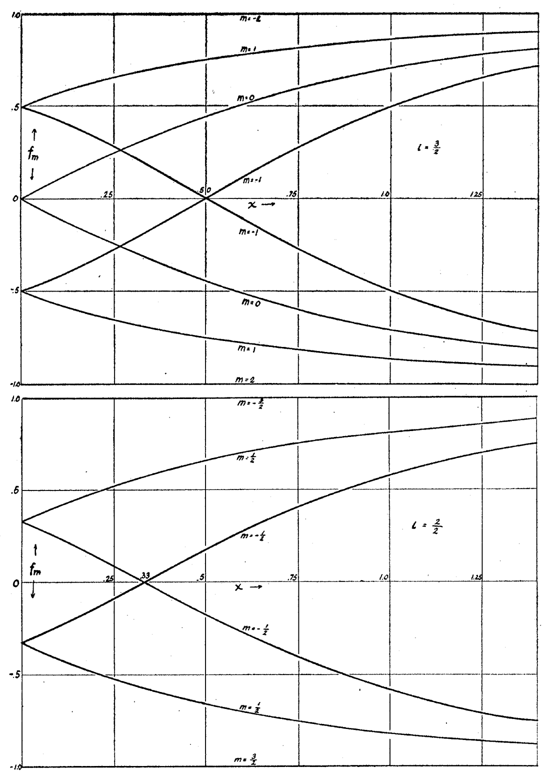


FIG. 1. Variation of effective magnetic moment, in units of μ_0 the Bohr magneton, of each magnetic level with $x = 2\mu_0 H/hc\Delta\nu$ for $i = 2/2$ and $i = 3/2$.

of the atom (with quantum number m) in units of μ_0, the Bohr magneton.

For values of x much greater than 1 the f_m's approach the values ± 1, the same as for $i=0$ and thus all effects of nuclear spin are lost, to within the precision of experiments of this type. For potassium this occurs at fields as low as 300 gauss. Strong effects due to nuclear spin are obtained only in the region where x is less than 1. This is shown in Fig. 1 where the f_m's are plotted as a function of x for nuclear spins 2/2 and 3/2. In particular $f_m = 0$ when

$$x = -2m/(2i+1), \quad [-(i-\tfrac{1}{2}) \lesseqgtr m \lesseqgtr 0]. \quad (3)^*$$

When $i > \frac{1}{2}$ there are values of x other than zero for which Eq. (3) is satisfied. Thus for certain values of H atoms of magnetic quantum number m satisfying Eq. (3) will have zero moment. If a beam of potassium atoms is allowed to traverse an inhomogeneous magnetic field all atoms possessing a magnetic moment other than zero will be deflected while atoms with zero moment will not be deviated from their paths. Hence if we station our detector in the beam and increase the field beginning with zero the number of atoms arriving at the detector will decrease (since $\partial H/\partial y$ increases with increasing H) until we get to the region of the field where some states have zero moment (Eq. (3)) when the intensity will rise to a maximum and decrease again for higher values of the field.

For either of the two spins mentioned we get only one maximum at a field other than zero. For H zero the intensity is at a maximum for any spin, since there is no deflection of atoms of any state when $\partial H/\partial y = 0$. Thus the mere determination of the number of maxima is not sufficient to define the spin. For example, one maximum implies a spin of either 2/2 or 3/2, two maxima, 4/2 or 5/2, etc. However when there are two or more maxima one can determine the spin from the relative values of the field at which these peaks occur. If there is only one peak we resort to analysis of the intensity distribution with respect to field at a position of zero deflection as well as to the analysis of the Stern Gerlach patterns at some definite value of the field.

In view of the known fact that $\Delta\nu$ of K^{39} is less than 0.02 cm^{-1} the region $x < 1$ corresponds to a field of less than 200 gauss. Since it was quite possible that $\Delta\nu$ was considerably less than that amount the apparatus had to be designed to attain a considerable deflection in fields as low as 5 gauss.

The deflection in the y direction of an atom in an inhomogeneous magnetic field is given by

$$s_m = (f_m/2Mv^2)(l_1^2 + 2l_1 l_2)\mu_0 \partial H/\partial y, \quad (4)$$

where l_1 is the length of the magnetic field and l_2 is the distance between the end of the field and the detector. The deflection of an atom with kinetic energy kT is

$$s_{\alpha m} = (f_m/4kT)(l_1^2 + 2l_1 l_2)\mu_0 \partial H/\partial y. \quad (5)$$

* Relations (1) and (3) are true for the case of normal hyperfine splitting (magnetic moment in the direction of the spin vector). If the splitting is inverted (magnetic moment pointing in opposite direction to that of the spin) we must substitute $-m$ for m. This method cannot distinguish between the two cases.

For an undeflected beam of trapezoidal shape the intensity at any point in the deflection pattern is given by

$$I=\frac{I_0}{d-p}\frac{1}{2(2i+1)}\sum_m[(s+d)e^{-s\alpha_m/(s+d)}+|s-d|e^{-s\alpha_m/|s-d|}-(s+p)e^{-s\alpha_m/(s+p)}-|s-p|e^{-s\alpha_m/|s-p|}], \quad (6)$$

where I_0 is the intensity at the center of the undeflected beam with the field zero, $2d$ is the width of the lower base of the trapezoid, $2p$ that of the upper base, and s is the distance of the point from the center of the original beam. For $s=0$, Eq. (6) reduces to

$$\frac{I}{I_0}=\frac{1}{(d-p)(2i+1)}\sum_m[de^{-s\alpha_m/d}-pe^{-s\alpha_m/p}]. \quad (7)$$

It is clear from (7) that if in the region of a maximum the contribution to the intensity is to come mainly from the atoms of zero moment we must have s_α for the atoms with nonvanishing moments large compared to d. Since the value of the field is limited and it is impracticable to extend the ratio of gradient to field indefinitely and since it is difficult to work with slits less than 0.01 mm wide, recourse must be had to lengthening the beam to obtain the desired resolution.

Apparatus

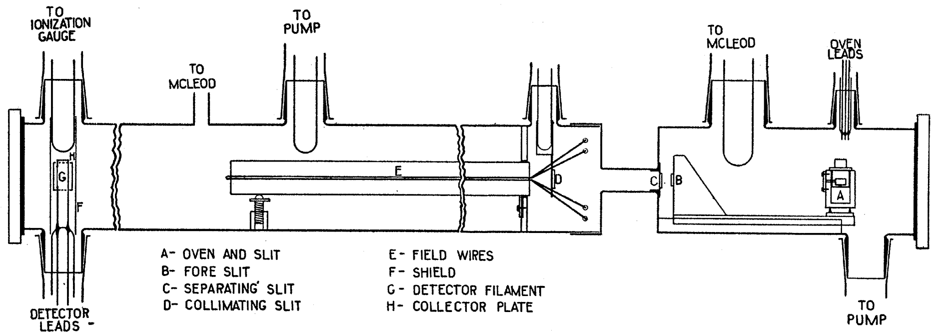
A schematic diagram of the apparatus is shown in Fig. 2(A). The oven, A, is identical in design with that used by Rabi and Cohen.[4] It is supported by three steel pegs mounted on a dovetail slide so that the oven can be moved and accurately replaced. On the same slide is mounted the slit B, which can be used as a collimating slit. However, in this experiment it was used as a fore slit. The oven slit is about 0.013 mm wide and that of B about 0.2 mm. The distance between the oven slit and fore slit is 18.4 cm. The slit C, about 0.15 mm wide, separates the oven chamber from the receiving chamber, permitting a difference in pressure in the two chambers to exist during a run. The chambers are made of brass cylinder $4\frac{1}{2}''$ O.D. and $\frac{1}{8}''$ thick and are pumped out separately by Apiezon B oil diffusion pumps. Because of the gas coming out of the heated oven the pressure in this chamber is not much better than 2×10^{-6} mm while in the receiving chamber it is about 7×10^{-7} mm. The pressure in the oven chamber is measured with a McLeod gauge while that in the receiving end is measured with both a McLeod and an ionization gauge.

The collimating slit, D, is made movable by mounting it on a ground joint. The slit width was generally kept at 0.02 mm. The block E holding the field wires is made of duralumin. At the end nearest the collimating slit it is held in place by a knife-edge at the bottom and is pressed against another knife-edge at the back by means of screws. The block is made to pivot about this end by supporting the other end on round-headed screws against which it is held by springs. The motion toward or away from the beam is achieved by rotating one of the supporting screws through a ground joint. The distance between the oven slit and the detector, G, is 141 cm and between the oven and collimating slits is 31.1 cm. The length of the field is 61.5 cm and the field free distance is 46 cm. The beam is detected by the surface ionization method[7] with a one mil tungsten filament, G, mounted eccentrically on a ground joint. The positive ion current is collected by the plate H and amplified by an FP-54 electrometer through a resistance of 2×10^{10} ohms.

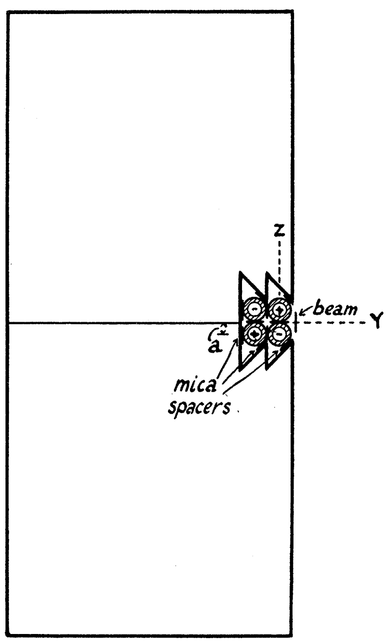
The inhomogeneous magnetic field is obtained from a system of parallel wires carrying current, as used by Rabi, Kellogg and Zacharias.[8] Fig. 2(B) shows a cross section of the duralumin block holding the wires. Here we have four wires instead of two. The outer wires are separated from the inner wires by mica strips and can be used separately. Thus when there is no current in the inner wires the field is exactly that used by R.K.Z. giving a ratio of $\partial H/\partial y$ to H of about 8 to 1 for the given diameter of the wires. If the inner wires are also used ratios as large as 11 to 1 and better homogeneity in H along the height of the beam are obtained. Fig. 3 gives a set of curves for both systems of conductors. For the four wire system I refers to the current in the outer wires (nearer the

[7] Taylor, Zeits. f. Physik **57**, 242 (1929).

[8] Rabi, Kellogg and Zacharias, Phys. Rev. **46**, 157 (1934).



(A)



(B)

FIG. 2(A) Diagram of apparatus. (B) Cross section of field block showing wire arrangement. + and − indicate opposite directions of current.

beam). For the cases $y=1.2a$ and $y=1.3a$ the current in the inner wires is $2.0\times I$ while for $y=1.4a$ this current is $2.2\times I$. The four wires are so arranged that their centers form a square of side $2a$. The value of a is 0.124 cm. The height of the beam in the field is limited by stops at each end to 1 mm, and over this region H and $\partial H/\partial y$ in the two wire system are constant to about 1 percent. All wires are hollow permitting cooling by water.

Although the four wire system was used during the course of the experiments whenever additional resolving power was required and proved to be of great aid in finding the K^{41} peak, the experimental curves reported in this paper were obtained with the two wire system.

The distance of the beam from the wire surfaces is determined in the following manner: The edge of a slit jaw, used as a fiduciary mark is attached rigidly to the oven end of the duralumin block and with the aid of a microscope is set at any desired distance from the wire surfaces. A telescope is then set up with its axis parallel to the line determined by the fiduciary mark and the center of the fore slit B. With the cross hair set at the fiduciary mark the collimating slit is moved until the center of the slit coincides with the cross hair. This fixes the distance at the oven end. The distance at the detecting end is obtained by mounting a two mil tungsten filament, parallel to the collimating slit, at the desired distance from the wire surfaces. When the original undeflected beam is obtained the detector is set at the center of the beam and the field block is moved until the filament stops the beam. The filament is then burned away.

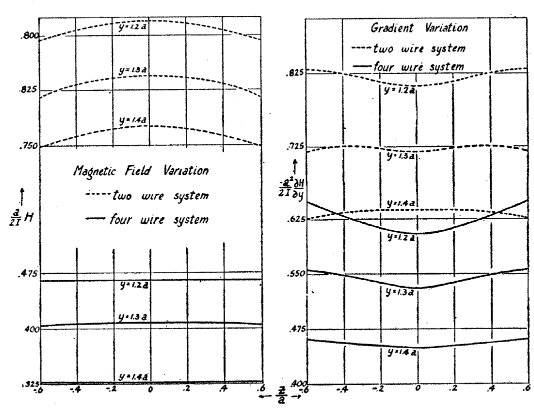


FIG. 3. Variation of magnetic field and gradient with position for two and four wire systems.

Procedure

A freshly-cut piece of potassium is placed in the oven and the system immediately evacuated. The oven temperature is raised at the rate of two degrees a minute to 325°C, reduced to about 300°C and stabilized. When conditions are steady an investigation of the undeflected beam is made by moving the detector in steps of about 0.02 mm and observing the corresponding beam intensity. The shape of the beam is in general in good agreement with that calculated from the slit widths and distances. The detector filament is then placed in the center of the beam and the intensities corresponding to different values of the applied magnetic field are observed.

A typical curve showing the variation of intensity at the center of the beam with respect to current in the field wires is shown in Fig. 4(A). At 63.3 amp. there is a fairly sharp peak having an intensity of 22.8 percent of that of the original undeflected beam. This ratio is accurately determined by taking alternate readings with field on and field off. The intensity at the region of 42 amp. is less than 3 percent. The irregularity in the curve at C is due to K^{41} as will be shown later. Fig. 4(B) is a plot of this region on a more suitable scale.

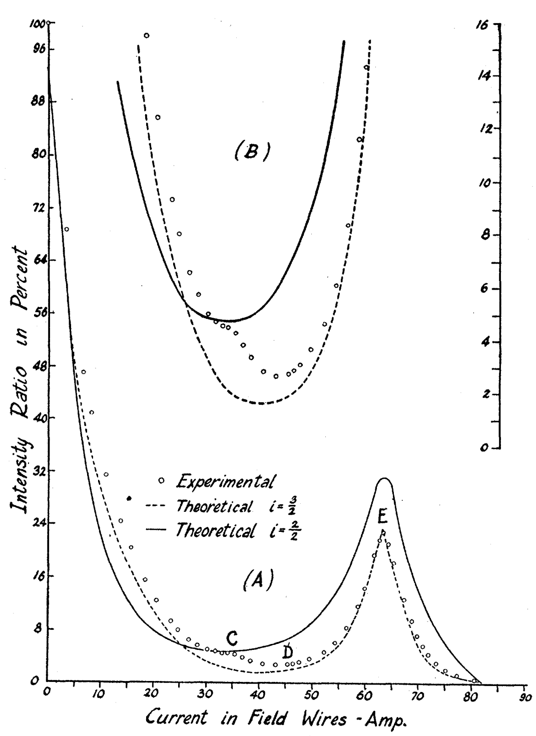


FIG. 4. (A) Variation of beam intensity with field at the position of zero deflection. 1 ampere = 1.29 gauss. (B) A portion of 4(A) with ordinates plotted to a larger scale to show the effect of K^{41} at C.

It is also of interest to obtain the deflection patterns for certain values of the field. This is done by keeping the current in the field wires constant and measuring the intensity at various points by moving the detector across the beam. Fig. 5 (full line) and Fig. 6 (circles) show deflection patterns taken in this manner.

Results

Nuclear spin of K^{39}

The smooth course of the curve of Fig. 4(A) excludes the possibility of a second peak of comparable size in the region of lower fields. From the theory of the experiment such a peak could occur only at values of the current equal to 31.6 amp. or 21.1 amp. Although the curve was carefully extended to above 200 amp. no other peak was found. Since K^{39} is present to the extent of over 90 percent these facts alone limit the spin of the K^{39} nucleus to either 2/2 or 3/2. To decide between the two possible values we resort to further analysis of the curves.

The theoretical value for the ratio I_w/I_0 of the intensity at the peak to that of the total beam intensity due to this isotope is $1/(2i+1)$, since there are in general $2(2i+1)$ different magnetic states of the atom, each equally probable, and the peak represents a place where two of these states have zero moment (Fig. 1). The deflection pattern at this value of the field is in fact a superposition of an undeflected beam of the same shape as the original beam, due to atoms with zero moment, on a deflected pattern due to the other components. This is clearly shown in Fig. 5. For a spin of 3/2, I_w/I_0 should be $\frac{1}{4}$ and for 2/2 the value for I_w/I_0 should be $\frac{1}{3}$. If we take the value 93.3 percent for the abundance of K^{39} as given by Brewer and Kueck[9] the intensity ratio at the maximum should be 23.3 percent for $i=3/2$ and 31.1 percent for $i=2/2$. The highest experimental ratio obtained is 22.8 ± 0.4

[9] Brewer and Kueck, Phys. Rev. **46**, 894 (1934).

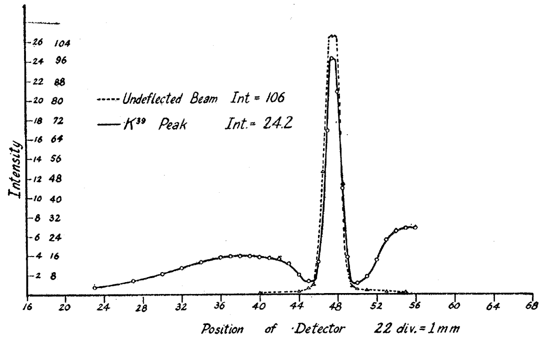


FIG. 5. Deflection pattern taken with field current equal to 63.3 amperes, the value at the peak at E, Fig. 4(A). The dotted curve is the beam with field off plotted to 1/4 the scale of the deflection pattern.

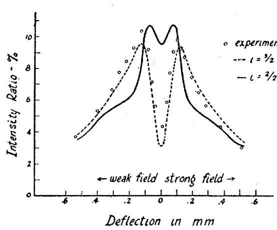


FIG. 6.

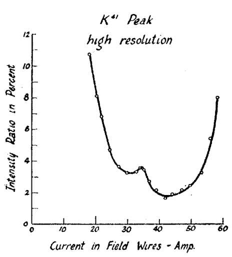


FIG. 7.

FIG. 6. Deflection pattern taken at field current corresponding to D of Fig. 4(A).
FIG. 7. Experimental curve as in Fig. 4 in region of K^{41} peak with high resolution.

percent, in good agreement with the theoretical ratio for a spin of 3/2 but not with the expected value for a spin of 2/2. Because of experimental errors in setting the field wires parallel to the beam by the method described above, a supplementary method must be employed to secure this result. The direction between the beam and field wires is varied in small steps by moving the collimating slit. At each stage the intensity at the peak is noted until the maximum ratio is obtained. This condition is easily reproducible. The value 0.228 was thus reproduced within the error stated in six distinct runs. Values lower than this ratio, ranging from 21 percent up, were obtained when the beam was not accurately parallel to the field wires.

Although different experimenters are not in agreement as to the abundance of K^{39}, Dempster[10] giving a value of 95 percent and Bainbridge[11] 92.6 percent, the differences are not of sufficient magnitude to weaken seriously the conclusions we draw from the intensity ratio at the peak.

Eqs. (1), (2), (5) and (7) will yield the intensities at points of zero deflection for various values of the current in the field wires if the relation between the parameter x and the current I is known. Since H is proportional to the current we may write $x=CI$. The position of the peak in the curve gives the proportionality factor C if the nuclear spin is known. For a spin of 3/2 the peak occurs at $x=\frac{1}{2}$ and for a spin of 2/2 the maximum is at $x=\frac{1}{3}$. Calculations are made by assuming each possibility in turn. A comparison between the calculated and observed curves is shown in Fig. 4. The calculated curves do not include the K^{41} isotope, i.e., the value of I/I_0 as calculated from Eq. (7) is multiplied by 93.3 percent, the assumed abundance of K^{39}. We see that the general shape of the experimental curve at the position of the peak as well as at the minimum region is in much better agreement with the calculated curve for a spin of 3/2 than with that for a spin of 2/2.

This method of deciding between the two spins is not particularly sensitive to errors in temperature, field gradient, or beam shape. Curves were calculated for both spins, with the individual s_{α_m}'s altered by ± 10 percent. It was found that although the intensity at any given value of the current changed, the shape of the curves changed very little, so that the calculated curves for $i=3/2$ were still in much better agreement with the experimental curve than those for $i=2/2$.

The deflection pattern taken at a field corresponding to point D in Fig. 4 offers another source of evidence for deciding between the two possible spins. Eqs. (1), (2), (5) and (6) can be applied to calculate the intensity at any distance from the center of the original pattern if the spin is known. There was no effort made in these experiments to obtain conditions such that the intensity calculations could be made with very high accuracy (accurate measurement of temperature, beam shape, etc.). We note in Fig. 6 that the general course of the experimental points bears little resemblance to the calculated curve for a spin of 2/2, but is in good agreement with the calculated curve for a spin of 3/2.

[10] Dempster, Phys. Rev. 20, 631 (1932).
[11] Bainbridge, J. Frank. Inst. 212, 317 (1931).

It should be mentioned that although K_2 molecules were looked for by the method of Lewis[12] no central peak greater than 0.4 percent of the total intensity was found at fields sufficiently high for the resolution of such a peak (120 gauss). This may be due to the following:

(1) Nonequilibrium conditions in the oven, due to temperature gradients between the oven slit and the interior, which would cause the dissociation of the molecules. This is the most likely reason since the oven heaters were closest to the slit.

(2) Because of the greater mass and larger cross section of the molecules they may have been scattered out of the beam to a far greater proportion than the atoms.

(3) The nuclear moment due to the molecular rotation[13] may have been sufficiently great to cause the molecules to be deflected.

Accordingly no corrections due to molecules have been made in any of the above calculations. However, even if one assumed that molecules were present to the extent found by Lewis (about 2 percent) they would have had no effect on the final results of these experiments.

$\Delta\nu$ of the $^2S_{\frac{1}{2}}$ state of K^{39}

With the value of the spin definitely fixed at 3/2, we may obtain at once the hyperfine structure separation $\Delta\nu$ of the normal $^2S_{\frac{1}{2}}$ state of K^{39} from Eq. (2). The value of the field at the peak is 81.5 gauss and therefore

$$\Delta\nu = 0.0152 \pm 0.0006 \text{ cm}^{-1}.$$

This is based on the determination of the distance of the beam from the field wires by the method described in the section under "Apparatus." In subsequent adjustment of parallelism of the beam to the wires the position of the beam with respect to the field wires is calculated from the measured value of the current at which the peak occurs.

The chief source of error is geometrical, incident to fixing the position of the beam relative to the field wires. The determination of $\Delta\nu$ is not affected by any errors in the measurement of temperature, field gradient, or beam shape. Neither does it depend on the assumption of Maxwellian distribution of velocities of the atoms in the beam. The value here reported is somewhat higher than the result 0.0147 cm^{-1} announced in the first report. The error in the latter determination was due to a shift in the collimating slit which was discovered when the apparatus was taken apart. In the subsequent experiments such a possibility was eliminated.

An independent measure of $\Delta\nu$ was obtained in the following manner. Sodium was substituted for potassium in the oven, and the peak located. Since the spin of sodium is the same as that of K^{39} the ratio of the value of the current at the peak for sodium to that of K^{39} is the same as the ratio of their respective $\Delta\nu$'s. With the value of 0.0583 for $\Delta\nu$ of sodium,[14] the value of 0.0151 was obtained for $\Delta\nu$ of K^{39}. The constancy of the geometrical factors was checked by sandwiching the sodium run between two potassium runs.

If we apply the formula of Goudsmit,[15] as modified by Fermi and Segrè,[16] for computing nuclear magnetic moments, using the value 3/2 for the spin of K^{39} and 0.0152 for $\Delta\nu$ we get

0.39 nuclear Bohr magnetons

for the magnetic moment of the K^{39} nucleus.

K^{41}

The experimental methods under consideration which have been applied to K^{39} are equally applicable, if sufficient resolution is obtained, to a mixture of isotopes. Since the value of the field at which the zero moments will occur for these isotopes will in general be different, one will obtain sets of peaks in a curve such as Fig. 4(A) corresponding to the different isotopes.[17] This is also true for a mixture of elements. In Fig. 4 the break in the curve at C can only be due to K^{41}. Under higher resolution, obtained by narrowing the slits to 0.012 mm, this break becomes a peak, as shown in Fig. 7, which is always found in the same place on the curve. This peak cannot be due to K^{39} because the intensity is too weak, and the peak is in the wrong position on the curve. It cannot be ascribed to contaminations by other alkali atoms since a pure

[12] Lewis, Zeits. f. Physik **69**, 786 (1931).

[13] Wick, Zeits. f. Physik **85**, 25 (1933); Estermann and Stern, Zeits. f. Physik **85**, 17 (1933).

[14] Granath and Van Atta, Phys. Rev. **44**, 935 (1933).

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

[16] Fermi and Segrè, Zeits. f. Physik **82**, 729 (1933).

[17] Rabi, Phys. Rev. **47**, 334 (1935).

tungsten surface at low temperature is capable of detecting only potassium, rubidium and caesium, and peaks due to rubidium and caesium cannot occur at such low field values. In fact the peak cannot be due to any impurities since there was no noticeable change in relative intensity after the oven had been heated for more than ten hours.

The height of the K^{41} peak is somewhat over 1 percent of the original beam. For such low intensities, it is difficult to apply the same considerations that have aided us in determining the spin of K^{39}. In the first place, due to insufficient resolution we cannot be certain that this is the only peak. Moreover, an accurate analysis of the course of the curve at the peak is not possible because of the presence of K^{39} to an extent which cannot be accurately calculated because of errors in the field gradient, temperature, and shape of original beam. However, we can state quite definitely that the spin of the K^{41} nucleus is greater than $\frac{1}{2}$, and that the ratio of the magnetic moment of the K^{41} nucleus to that of the K^{39} nucleus can be put between the limits

$$0.42 < \mu_{K^{41}}/\mu_{K^{39}} < 0.88,$$

depending on the spin.

Discussion

While this work was in progress, Jackson and Kuhn[18] succeeded in measuring the hyperfine structure separation of the resonance lines of K^{39} in absorption using a molecular beam to cut down the Doppler effect. The value which they calculated for $\Delta\nu$ of the normal state of K^{39} is 0.0152 cm^{-1}, in excellent agreement with our result for $\Delta\nu$. They did not succeed in determining the spin uniquely, but infer from their judgment of intensity of the hyperfine structure lines that the spin of the K^{39} nucleus is probably greater than 3/2. It is clear from our experiments that the spin of K^{39} cannot be greater than 3/2. It should be pointed out that this independent measure of $\Delta\nu$ from hyperfine structure may be used in our experiment as an additional source of evidence in deciding between a spin of 3/2 and 2/2. Inserting in Eq. (2) this value of $\Delta\nu$ and the value of the field at the peak we obtain at once the value of 0.50 for x at the peak and therefore $i = 3/2$.

The theory of our experiment depends on the cosine law of interaction between the angular momentum vectors of the nucleus and the external electrons. The value of $\Delta\nu$ which we obtain is a consequence of this assumption. The $\Delta\nu$ as measured by hyperfine structure is practically independent of this assumption. It is therefore interesting to note that the excellent agreement between the deflection and spectroscopic values for $\Delta\nu$, despite the fact that the magnetic moment of K^{39} is quite small, is strong evidence for the cosine law of interaction in the case of K^{39}.

In conclusion, the writer wishes to express his indebtedness to Professor I. I. Rabi for suggesting the problem and following these experiments with keen interest and helpful discussions, to Mr. Marvin Fox for his invaluable assistance throughout the course of the research, and to his other colleagues in the molecular beam laboratory for many helpful suggestions.

[18] Jackson and Kuhn, Proc. Roy. Soc. **A148**, 335 (1935).