The Nuclear Spin and Magnetic Moment of K^{40}

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The molecular beam magnetic resonance method has been employed to observe the nuclear spin and the h.f.s. $\Delta\nu$ of K^{40}. The apparatus and procedures of this experiment are different from those previously employed in the magnetic resonance method because of the small natural abundance of K^{40} and because both the nuclear spin and h.f.s. $\Delta\nu$ were previously unknown. The spin is shown to be 4 and the h.f.s. $\Delta\nu = 1285.70 \pm 0.1$ megacycles per second. The doublet is inverted. By comparison with the known nuclear moment of K^{39}, the nuclear moment of K^{40} is taken to be -1.290 nuclear magnetons.

BECAUSE of the abnormally long half-life of the beta-activity of potassium, it has long been suspected that the nuclear spin of K^{40} is large and integral. Even before Smythe and Hemmendinger[1] had shown that the radioactivity of potassium is undoubtedly due to K^{40}, it was indicated by Bethe and Bacher[2] that the long lifetime is not in contradiction with the Fermi beta-ray theory. The success of their argument depends on the assumption of a nuclear spin of 3 or 4, and since nuclear spins up to 9/2 were known, there was no particular objection to this. However, until the present experiment no successful attempt to observe the nuclear spin of K^{40} has been reported, although at least one serious attempt by Millman and Rabi† was made by the well-known molecular beam method of zero moments. All this is doubtless due to the small natural abundance of K^{40} given by Nier[3] as one part in 8600.

A preliminary report[4] of the results to be given in this paper has already been presented before the American Physical Society, and it was there given that the nuclear spin of K^{40} is indeed 4, and further that the nuclear magnetic moment is large (1.29 nuclear magnetons) and negative. The experimental method is a modification of the molecular beam magnetic resonance method which follows in many details the experiments described by Kusch, Millman, and Rabi[5] in a paper called "The Radiofrequency Spectra of Atoms," and hereinafter referred to as KMR. They report observations of the hyperfine structure for the atoms of Li^6, Li^7, K^{39}, and K^{41} and its Zeeman effect and Paschen-Back effect. In subsequent papers they have also studied Na, Rb, and Cs. Their observations are of two types, which can easily be understood by referring to Figs. 1 and 2, which represent the energy levels of an alkali atom in a magnetic field; Fig. 1 for a spin of $\frac{3}{2}$ and Fig. 2 for a spin of 4. These two figures should be enough to show the type of behavior for any spin.

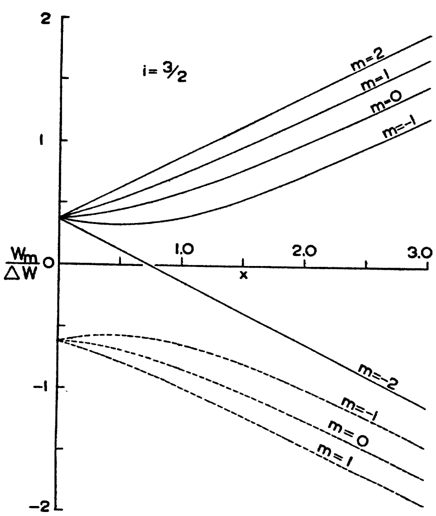

FIG. 1. Diagram of the energy levels of an atom with electronic angular momentum $J=\frac{1}{2}$ and nuclear spin $I=\frac{3}{2}$. The full curves are for the large $F=2$; the dotted curves are for $F=1$.

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[1] W. R. Smythe and A. Hemmendinger, Phys. Rev. **51**, 178 (1937).
[2] H. A. Bethe and R. F. Bacher, Rev. Mod. Phys. **8**, 82 (1936). See p. 196.
† Never published.
[3] A. O. Nier, Phys. Rev. **48**, 283 (1935).
[4] J. R. Zacharias, Phys. Rev. **60**, 168 (1941).
[5] P. Kusch, S. Millman, and I. I. Rabi, Phys. Rev. **57**, 765 (1940).

In Figs. 1 and 2 each energy state is specified by a value of $F=(I+\frac{1}{2})$ or $(I-\frac{1}{2})$ and the magnetic quantum number m. Those characteristic features of these curves which are the same for atoms with different nuclear spin or magnetic moment are:

(1) The number of states for either F is $2F+1$.

(2) In a magnetic field stronger than that given by $x=1$, all but one of the states with the larger F increase in energy with increasing field, and all of the states with the smaller F decrease in energy with increasing field. Thus the only possible transition between two adjacent states with the same F but with opposite sign for the atomic moment in high field is that between $m=-(I+\frac{1}{2})$ and $m=-(I-\frac{1}{2})$.

(3) In a given weak field the intervals between adjacent levels are all equal and equal to $(g_J-g_I)\mu_0H/(I+\frac{1}{2})$. As will be indicated later the small term g_I provides a means of finding the sign of the nuclear moment.

(4) The diagrams are drawn for atoms with positive nuclear moment. For negative moment or inverted h.f.s. doublet the diagrams are inverted in the following respects: in weak field, states with the larger F have the smaller energy and the spacing about zero is inverted; item (2) above should read: in strong field, all states with smaller F increase in energy with increasing field, and all but one of the states with larger F decrease in energy with increasing field; the signs of all m's are reversed so that the adjacent pair of states with different sign of moment in high field are $m=(I+\frac{1}{2})$ and $m=(I-\frac{1}{2})$. All of the arguments of the present paper will be given with the notation for positive nuclear moment and with that diagram in mind.

One of the methods used by KMR[5] was to observe the frequencies associated with transitions between the two F levels of the h.f.s. doublet in very weak magnetic field. This yields a set of lines, the center of gravity of which is the h.f.s. $\Delta\nu$ itself and, if the magnetic field in which transitions occur is sufficiently weak, the spacing between adjacent members of the set of lines is $(g_J-g_I)\mu_0H/h(I+\frac{1}{2})$. Their other procedure was to observe the frequencies associated with transitions in strong field of $m_F(\Delta m_F=\pm 1)$ with constant F. These lines occur at a frequency $\Delta\nu/(2I+1)$ if the field is sufficiently strong. Both of these methods of observation require some fore-knowledge of the h.f.s. $\Delta\nu$ in order to know in what part of the electromagnetic spectrum to search for transitions.

The present experiment differs from those of KMR on the other alkali atoms in that neither the nuclear spin nor the h.f.s. $\Delta\nu$ was known at all before starting the experiment. And also, since the natural abundance of K^{40} is so small, a gross search for radiofrequency spectral lines for K^{40}

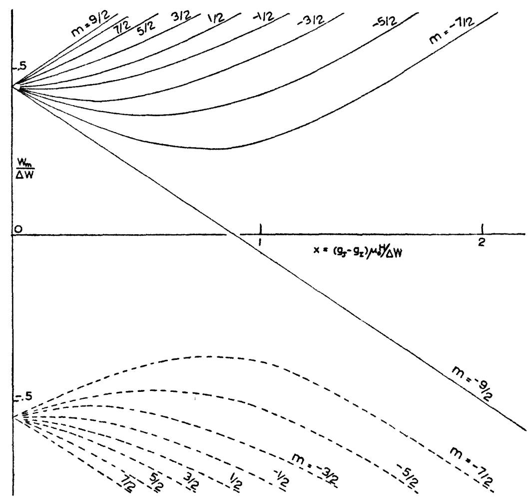

FIG. 2. Diagram of the energy levels of an atom with electronic angular momentum $J=\frac{1}{2}$ and nuclear spin $I=4$. The full curves are for the larger $F=9/2$; the dotted curves are for $F=7/2$.

in the presence of those of K^{39} and K^{41} would be futile. However, there is little doubt that the nuclear spin of K^{40} with even atomic weight is integral and therefore different from the spin of K^{39} and K^{41} which is $\frac{3}{2}$. The following method was therefore devised.

The transition selected for use in this investigation is that between the two states $m_F=-(I-\frac{1}{2})$ and $m_F=-(I+\frac{1}{2})$ for $F=(I+\frac{1}{2})$ (see Fig. 1 or 2). The energy required for this transition in weak field is $(g_J-g_I)\mu_0H/(I+\frac{1}{2})$ and except for the almost negligibly small term g_I is independent of the nuclear magnetic moment and of the h.f.s. $\Delta\nu$ to which it gives rise. That is, if the magnetic field is so weak that the coupling between the nucleus and the atomic electrons is not broken then the atom behaves as though its angular momentum is $(I+\frac{1}{2})$ and the tightness of the coupling makes no difference. Thus in a

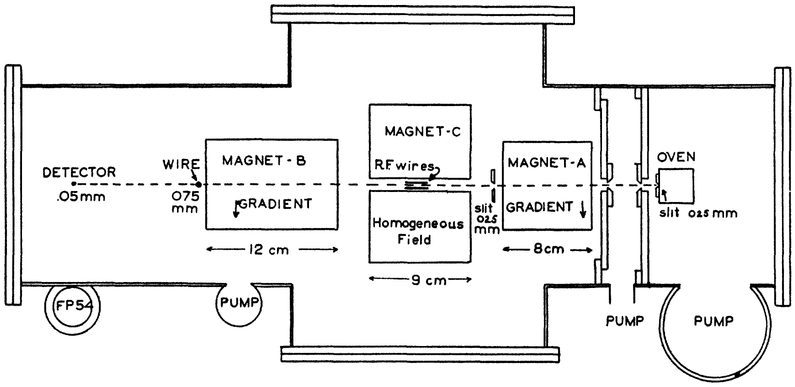

FIG. 3. Schematic diagram of apparatus.

sufficiently small magnetic field, transitions of the type referred to will occur at different frequencies for atoms with different nuclear spins, and at the same frequency for atoms with the same spin regardless of the $\Delta\nu$. And since the only other alkali nucleus with integral spin is Li^6, it is possible to isolate K^{40} in spite of its small natural abundance.

APPARATUS

Figure 3 is a schematic diagram of an apparatus constructed especially for experiments of this type. As in all molecular beam magnetic resonance experiments on alkali atoms, the molecular beam originates in an oven with a narrow slit covering its aperture. In this case the slit height is 1 cm and the width 0.025 mm so as to obtain a strong beam. The chamber in which the oven sits is pumped at 100 liters/sec., and is isolated from the main body of the apparatus by two slits which are adjustable for width and position by means of external screws. The beam is defined as usual by a collimating slit situated between magnets A and C and set at a width of 0.025 mm. The tungsten detecting filament (0.05-mm diameter) is altogether 50 cm from the oven. This is the shortest beam so far used for the magnetic resonance method and the total beam intensities are correspondingly very high (about 10^{-9} amp. at beam center).

The iron electromagnets A and B provide inhomogeneous fields with a ratio of gradient to field of about 1.2 over a beam height of 1 cm. This was obtained by suitable choice of circular milling cutters used to shape the pole pieces. These magnets are similar to those used by Millman, Rabi, and Zacharias[6] except that the dimensions were chosen to suit the peculiarities of this experiment. Thus, to reach the fields required, twenty turns of copper tubing were used instead of four. Magnet C has flat pole pieces 6 mm apart and provides a very uniform field over the beam height and that part of the path which is occupied by the radiofrequency transition field. The deflecting magnets A and B have their gradients in the same direction so that a beam of alkali atoms will be so strongly deflected that none strikes the detector. Scattering of the beam by the small amount of residual gas in the apparatus prevents reduction of the beam intensity below 0.1 percent. Even this requires placing a thin obstacle wire in the direct line of the beam to cut out any alkali molecules which would not be deflected by the magnets. If the radiofrequency field is set at a value for producing a transition accompanied by a change of the sign of the total atomic magnetic moment, then those atoms will be refocused by the magnet B and will detour around the obstacle wire and fall on the detector. Thus in this apparatus magnetic transitions appear as peaks of beam intensity.

The reason for this departure from the usual procedure of the molecular beam magnetic resonance method is obviously to be found in the small abundance of K^{40}. The transition selected for study is that between $m=-(I+\frac{1}{2})$ and $m=-(I-\frac{1}{2})$ for which the net atomic moments

[6] S. Millman, I. I. Rabi, and J. R. Zacharias, Phys. Rev. **53**, 384 (1938).

have opposite sign in the high magnetic fields used for deflecting and refocusing. Thus, it is just these states that can be made to detour about the obstacle wire and only with the aid of the obstacle wire to cut out the beam was it possible to make the background intensity sufficiently low so that a peak due to K^{40} would stand out above the fluctuations of the background.

The radiofrequency field is produced in the central portion of the homogeneous field magnet C by means of a loop of wire similar to that used in other magnetic resonance experiments. This experiment was conducted with two different loops, both of which were capable of producing the r-f field over the beam height of 1 cm. The first loop used was made of two strips, 3 cm long, of half-inch by sixteenth-inch copper spaced 1 mm apart. By slotting and soldering, these were made to be water cooled. The r-f current is fed in at one end of one strip and out the same end of the other strip. Thus the beam is in the r-f field for 3 cm. The other loop was made simply by bending a piece of half-inch by sixteenth-inch copper into the form of a vertical hairpin without water cooling. For this one the r-f field traversed by the beam is only one-half inch long.

PROCEDURE

A beam of atomic potassium is obtained and the slits are set in line having been made vertical previously by optical means. This is especially important because the obstacle wire cannot be very much broader than the beam but must block it completely. The obstacle wire was itself a plumb line of number 40 copper wire with a small amount of soft vacuum wax at the point of its support to provide the necessary damping. The obstacle wire can be accurately centered in the beam by adjusting its position until on moving the detector filament to either side of the beam center the same intensity is read. It is only after this procedure is carefully followed that the amount of residual beam at the central position is small enough to make the experiment possible.

The magnets A and B are then turned on and the beam intensity reading rises. This can occur for several reasons. First, atoms which are scattered in the oven chamber and which are not in the geometrical line of the beam can be deflected onto the detector by the magnets. Second, transitions of atomic magnetic moments could occur in the space between the magnets A and B because of collisions with other molecules (improbable), or because of sudden changes in value or directions of magnetic fields near the entrances to the various magnets. In fact, this last effect can be made extraordinarily large by reducing the magnetic field in the magnet C to some value near zero. With all of these effects, except the last, the beam still reads less than 0.1 percent of the original beam if the vacuum is good and the lineup is careful.

The radiofrequency oscillator is set at a convenient frequency, say, 4 megacycles and the current in magnet C is adjusted until a transition is observed by a sharp rise in the beam current. If this rise of intensity depends on the frequency of the r-f oscillator then since the nuclear spins are the same, the transition of m_F from -2 to -1 for both K^{39} and K^{41} is probably being observed. If the magnetic field were readily determined then this fact could be checked immediately. Because of hysteresis the magnet calibration against ampere turns is of no use at low fields and the following indirect method of checking is used. If the frequency of the r-f oscillator is raised, then the magnetic field must be correspondingly increased to observe transitions. If this process of increasing the field and frequency is continued, then the single observed transition becomes double, one large peak and one small peak. The large one is attributed to K^{39} and the small one to K^{41} since the nuclear spins are the same but the h.f.s. $\Delta\nu$'s are different. Since the h.f.s. $\Delta\nu$'s of both of these nuclei are known one of the peaks can be used to calculate the value of the field (by use of the Breit-Rabi formula) and the frequency for the other can be predicted. After this procedure was followed several times it became easy

TABLE I. Observed frequencies of peaks attributed to K^{40} with the corresponding frequencies for transitions of K^{39}. In the limit of small field the ratio ν_{40}/ν_{39} should approach 4/9. These observations were made with r-f field wires 4 cm long by 1 cm high.

ν_{39} Mc	ν_{40} Mc	ν_{40}/ν_{39}	ν_{39} Mc	ν_{40} Mc	ν_{40}/ν_{39}
3.924	1.72	0.442	11.40	4.87	0.427
3.88	1.714	0.442	16.18	6.775	0.419
5.92	2.575	0.441	17.007	7.096	0.418
7.896	3.405	0.432	32.034	12.87	0.402

to tell immediately that the observed peaks were due to the transitions mentioned above.

In searching for K^{40}, a procedure somewhat similar to the above was followed. First a magnetic field was set and determined by observing the transition (m_F from -2 to -1) for K^{39} at a frequency ν_{39}. If the field is weak then $H=2h\nu_{39}/\mu_0$. The field is held constant and the frequency of the r-f oscillator is changed to the value appropriate to K^{40} under the assumption that its spin is some integer 0, 1, 2, 3, 4, 5, or 6. These frequencies bear a simple relation to the frequency, ν_{39}, used for K^{39}, i.e., $\nu_{40}=\nu_{39}(I_{39}+\frac{1}{2})/(I_{40}+\frac{1}{2})$. We neglect g_I compared with g_J and the decoupling which shows itself in the curving of the state $m_F=-(I-\frac{1}{2})$. Thus assuming that the nuclear spin of K^{40} is 4, then for the same magnetic field we have $\nu_{40}=\nu_{39}4/9$.

RESULTS

The procedure outlined above was followed for assumed values of the spin of 0, 1, 2, 3, 4, 5, and 6. For none of these except 4 was there any sign of transition. For spin 4 the data are exhibited in Table I. The changes of beam intensity which occurred for the values of the frequencies ν_{40} were completely consistent with the known natural abundance but were not large enough to measure precisely nor to show resonance curves. The reason for this is as follows. Although the maximum possible amount of beam refocused for the observed transitions of K^{39} is 25 percent of original beam intensity, only 10 percent is observed because of the presence of the obstacle wire. That is, the gradients of the magnets were too small to force all atoms about the obstacle wire. For K^{40} with spin 4 the maximum possible amount to be expected is 11 percent of the total K^{40}-beam which is only 1/8600 of the beam. Thus only 5 parts in 10^6 of the main beam are expected to appear as a peak for K^{40} against a background of about 0.1 percent. This background therefore had to remain constant to 1 part in 200, just to allow a peak to be observed. It is possible to make observations by turning the r-f oscillator off and on and noting the galvanometer deflections. This procedure makes it important to have the FP54 detector (sensitivity 5×10^{-17} amp./mm) insensitive to the r-f oscillation. Very careful shielding and by-passing of leads made this possible at all but a few frequencies for which parts of the apparatus resonate to the r-f. Because of the wide frequency range this requirement was difficult to meet.

TABLE II. Observed frequencies of peaks attributed to K^{40} with the corresponding frequencies for transitions of K^{39}. These observations were made with r-f field 1 cm long by 1 cm high. The values of the magnetic field were calculated from the frequencies for K^{39} by means of the Breit-Rabi formula. The column labeled denominator of Eq. (1) is listed to indicate the precision of the calculated values of the h.f.s. $\Delta\nu$'s. They are all reliable to about ±0.01. Thus the precision of the calculated $\Delta\nu$ values is inversely proportional to these denominators.

ν_{39} Mc	ν_{40} Mc	Magnetic field calc. gauss.	denom. Eq. (1)	h.f.s. $\Delta\nu$ of K^{40} assumed positive	assumed negative
17.040	7.157	22.19	0.32	1226.	1260.
29.974	12.118	36.52	0.86	1254.	1276.
31.840	12.805	38.45	0.96	1260.	1280.
42.608	16.688	48.99	1.57	1269.	1283.
42.624	16.666	49.00	1.56	1274.	1288.
42.632	16.677	49.01	1.57	1268.	1282.
42.660	16.687	49.04	1.57	1269.	1284.
125.50	42.760	110.21	8.79	1280.0	1285.6
125.608	42.777	110.27	8.79	1281.9	1287.6
125.615	42.780	110.27	8.79	1281.7	1287.4
125.636	42.792	110.28	8.80	1281.0	1286.7
388.96	124.32	236.33	51.48	1284.6	1286.4
389.00	124.35	236.34	51.51	1284.2	1285.8
389.00	124.37	236.34	51.51	1284.2	1285.8
389.10	124.397	236.39	51.57	1284.0	1285.5
389.14	124.418	236.40	51.57	1283.9	1285.4
389.48	124.53	236.55	51.63	1284.1	1285.6
389.50	124.57	236.55	51.67	1283.5	1285.0
389.96	124.691	236.74	51.72	1284.9	1285.7
390.86	125.02	237.12	51.95	1283.9	1285.4

Table I shows that the observed ratio ν_{40}/ν_{39} does not remain quite constant as the field is increased. This arises because, for the fields used, decoupling of the nuclear spin and the atomic electrons is beginning for both K^{39} and K^{40}. One should be able to calculate the h.f.s. $\Delta\nu$ of K^{40} from this observed departure from constancy. but this set of data is not sufficiently good for the purpose for two reasons. First the chief cause of the departure is the h.f.s. decoupling of K^{39} and the second the data are not sufficiently accurate because they were taken with a length of r-f field for which the magnet was not sufficiently uniform. Consequently a smaller r-f region was used, by using smaller wires for the r-f and the data of Table II were taken. Table II is a summary of data taken to determine the h.f.s. $\Delta\nu$ of K^{40} and at the same time to demonstrate that the resonances observed are really consistent with the assumption of an atom with a nuclear spin of 4.

Table II contains values of the h.f.s. $\Delta\nu$ of K^{40} obtained when we assume that the nuclear moment is positive (tabulated in the fifth column) and negative (sixth column). These calculations are made with the use of the Breit-Rabi formula, which for these purposes can be put in the following convenient form:[7]

$$\Delta\nu=(\nu-g_Ik)(g_Jk-\nu)/\{(\nu-g_Jk)-(g_J-g_I)k/9\}. \quad (1)$$

In this formula all symbols refer to K^{40} except k which is given by

$$k=\Delta\nu_{39}x_{39}/(g_J-g_I)_{39}$$

with

$$x_{39}=(g_J-g_I)\mu_0H/\Delta\nu_{39}.$$

Since H is determined by observing the $(m_F=-2)\rightarrow(m_F=-1)$ transition for K_{39}, it is more convenient to eliminate it in terms of the observed quantity ν_{39} by writing

$$x_{39}=(\beta^2-1)/(2\beta-1),$$

where

$$\beta=1+2(\nu-g_Ik)_{39}/\Delta\nu_{39}.$$

The actual procedure followed in applying this formula is first to use it without the small correction terms in g_I; then with this preliminary value of $\Delta\nu_{40}$ and the known values of g_I and $\Delta\nu_{39}$ for K^{39} to calculate a preliminary value of the g_I for K^{40}. This value of g_I is sufficiently accurate for the small terms but the sign of the correction terms is not known. The final calculations are made with both positive and negative sign. Thus inspection of columns 5 and 6 of Table II shows these results and that they are self-consistent for the nuclear moment taken negative (g_I positive) whereas they are inconsistent if it is taken positive (g_I negative). The weighted average of the values for the case of negative moment [weight proportional to the denominator of Eq. (1)] is 1285.65 Mc and the nuclear moment is taken to be negative.

Since the values of the $\Delta\nu$ obtained when a positive nuclear moment is assumed are inconsistent with each other by only a few times the possible errors of observation, it was decided to try to observe some other transition to obtain an independent value of the $\Delta\nu$ and if possible, a more precise one. The first obvious transition to try is that between the states $F=(I+\frac{1}{2})$; $m_F=(I-\frac{1}{2})$ and $F=(I-\frac{1}{2})$; $m_F=-(I-\frac{1}{2})$ at a field for which the jump is smallest for then the value of H need not be known well, and the determination of $\Delta\nu$ is as accurate as the observed transition frequencies. But this transition is one involving no change of m_F and if the radiofrequency field is perpendicular to the steady field, this transition would be highly improbable.[8] If K^{40} were an abundant isotope, this would be no great drawback, especially because the transition would occur at a not too difficult radiofrequency (obtainable with a 316-A oscillator) and with abundant isotopes transitions of this type are easily observed. In the present case it was decided to try the two transitions given by $m_F=-7/2$ to $m_F=-5/2$ for $\Delta F=\pm 1$. These states have maxima or minima for some value of the field and for a value of the magnetic field halfway between the maximum for one of the states and the minimum for the other the intervals mentioned above are independent of field and furthermore these are allowed transitions with the present type of r-f field and, in fact, were observed.

Through the kindness of Dr. Fay of the Bell Telephone Laboratories a 368-A oscillator tube was made available before they were generally obtainable and the required frequency near 950 Mc was obtained. On several occasions a pair of very small close peaks were observed. As previously described, observation of these peaks was made by noting galvanometer deflections as the oscillator was turned on and off. One of the chief difficulties with this experiment was associated with keeping the oscillator frequency sufficiently constant during an observation and making it come back to any desired frequency when turned back on. This is true because the theoretical half-width of the expected peaks is about 1/20,000, and it was not possible to obtain enough r-f current to make the half-width larger than that. However, once the reality of the peaks was established the precision of the calculated $\Delta\nu$ was then as good as the readings of the heterodyne wave meter. The separation between the peaks is very small (1 part in 10^4) and could not be

[7] S. Millman and P. Kusch, Phys. Rev. **58**, 438 (1940), Eq. (2).

[8] H. C. Torrey, Phys. Rev. **59**, 293 (1941). See Eq. (19).

observed well. However, as was expected it was possible to observe that the frequencies of these lines were not dependent, in first order, on the magnitude of the magnetic field. This fact substantiates the remark that the observed lines are associated with the transitions to which they are attributed. Also if this insensitivity to value of field were not true, then the lines would not be so sharp because the field is certainly not homogeneous to 0.01 percent. The average of three sets of data gives for the center of the pair 949.43 Mc which yields for the $\Delta\nu$ 1285.74 Mc. In this calculation the Breit-Rabi formula can be used directly and without any assumption of the magnitude or sign of the nuclear moment of K^{40}. Comparing this with the weighted average of the values given formerly 1285.65 Mc, it is easy to see that the negative nuclear moment is the proper one.

Averaging these two values, with no reason to give either one the greater weight, we write $\Delta\nu_{40}=1285.70\pm0.1$ Mc. To evaluate the nuclear moment of K^{40} from this value of the $\Delta\nu$, we make use of the experimental proof by Millman and Kusch[9] for the isotopic pairs Li^6, Li^7, Rb^{85}, Rb^{87}, that the ratios of the nuclear moments as observed by "molecular beam method" are equal to the h.f.s. $\Delta\nu$ ratios, due account being taken for the effect of nuclear spin. Thus we use $\Delta\nu_{39}=461.75$ Mc and $\mu_{39}=0.391$ nuclear magneton and obtain $\mu_{40}=-1.290$ nuclear magnetons, and 0.323 for the nuclear g.

Some discussion is necessary to show why it is believed that the substance giving rise to the peaks in this experiment is indeed K^{40}. First the observed intensity agrees as well as could be expected with the known abundance. Second the detecting filament will respond when cleaned of oxide coat only to elements with a lower ionization potential than sodium. There was no appreciable quantity of the known isotopes of Rb and Cs which have low enough ionization potential, but since they have known spins and moments they would be directly identifiable. Therefore a hitherto unknown isotope of either Rb or Cs could not be present in large enough quantity to have been observed. Third there was no dependence of the observed intensity of the small peaks to the temperature of the oven and it can be concluded that the substance has a vapor pressure of the same order of magnitude as that of potassium.

Although it was not surprising in view of the arguments from beta-ray theory that the spin of K^{40} is large and integral, some use has been made of the fact that the spin is 4 and not 3. Marshak[10] has shown that this spin adds support to the Gamow-Teller theory. On the other hand the large negative moment, as discussed recently by Inglis, does not seem to be readily understandable on a simple nuclear model. In view of the excellent self-consistency of the data for the assumption of negative moment there is little doubt about the correctness of this experimental result. It is of course natural to desire a determination of the sign of the nuclear moment such as was made by Kellogg, Rabi, and Zacharias[11] for H and D or that of Millman[12] by the magnetic resonance method which does not depend on a precise determination of the h.f.s. $\Delta\nu$. With the small abundance of K^{40} these methods do not at the moment seem feasible.

I wish to thank Professor I. I. Rabi, Dr. T. C. Hardy and the other members of the molecular beam laboratory for their assistance and encouragement during this experiment.

[9] S. Millman and P. Kusch, Phys. Rev. **60**, 91 (1941).

[10] R. E. Marshak, Phys. Rev. **59**, 957 (1941).

[11] J. M. B. Kellogg, I. I. Rabi, and J. R. Zacharias, Phys. Rev. **50**, 472 (1936).

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