THE NUCLEAR SPIN OF POTASSIUM

By F. W. Loomis[1] and R. W. Wood[2]
The Alfred Loomis Laboratory, Tuxedo Park, New York

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Abstract

Photographs of certain bands in the absorption spectrum of the potassium molecule show branches with alternating intensities. Moreover, comparison of the line spacings with those calculated by extrapolating observations on lithium and sodium show that all lines of each branch are present and the phenomenon of alternating missing lines does not occur. This disproves the assertion, based on failure of certain observers to find hyperfine structure, that the nuclear spin of K^{39} is zero.

RECENTLY searches have been made for hyperfine structure of potassium arc lines by Schüler and Brück[3] and of spark lines by Frisch.[4] In neither case was any hyperfine structure detected. The conclusion has been drawn,[5] that the nuclear spin of the principal isotope of potassium, K^{39}, is zero. This, if true, would be of considerable significance because it constitutes one of the very few reported exceptions to Heitler and Herzberg's rule[6] that the spins of the nuclei are even or odd multiples of half a Bohr unit according as the number of protons in the nucleus is even or odd.

The authors have therefore thought it worth while to attack the problem by the method of band spectra; that is, to determine whether or not alternate lines of the K_2 band spectrum are missing as they should be if the nuclear spin is zero.

It is true that measurements and analyses of the rotational structure of the potassium molecule have already been reported by Smith[7] and by Fredrickson and Watson;[8] but these were made in the same way and published at the same time as their analyses of the molecular spectra of sodium, and we have since shown[9] that the spectroscopic resolution of both investigators was insufficient, the "series" illusory and the reported constants wholly meaningless. It seemed probable that this was also true of their measurements of the potassium spectrum, and the present investigation has shown that this is in fact the case.

The spectrum was photographed in the fourth order of the Tuxedo laboratory forty foot spectrograph, using a particularly fine seven-inch plane grat-

[1] The University of Illinois.
[2] The Johns Hopkins University.
[3] Schüler and Brück, Zeits. f. Physik **58,** 735 (1929).
[4] Frisch, unpublished, but mentioned by Frisch and Kronig.[5]
[5] Frisch and Kronig, Naturwiss **19,** 444 (1931).
[6] Heitler and Herzberg, Naturwiss **17,** 673 (1929).
[7] Smith, Proc. Roy. Soc. **A106,** 400 (1924).
[8] Fredrickson and Watson, Phys. Rev. **30,** 429 (1927).
[9] Loomis and Wood, Phys. Rev. **32,** 223 (1928).

ing with 15000 lines per inch. The spectrograph has recently been completely thermostated and the mounting redesigned by Mr. Alfred Loomis and is now very convenient to operate and capable of giving high definition with long exposures.

The potassium was contained in an iron tube, with windows fastened to the ends with sealing wax, evacuated to a few millimeters of residual gas (principally hydrogen), heated at the center with a flame and cooled at the ends with water to protect the windows. It is necessary to adjust the temperature rather closely, so that the band spectrum is developed, but does not become too complex. The solar spectrum was used as a source and also as a comparison. The absorption spectrum of potassium was photographed in the region from 6440 to 6700A, which region contains the strong (2,0) (1,0) (1,1) (0,1) and (0,2) bands of the red system, and other weak ones.

Some of the bands, notably the (0,2) band, are so well resolved that it is possible to pick out the consecutive lines of a branch on mere examination of the plate. In these branches a definite alternation of intensities can be seen. It persists over the whole of the region which is free from overlapping bands and the only lines which do not fit into it are those for which there is evidence of superposition. There can be no doubt that the alternation is real. Moreover, the lines are obviously members of a single branch, probably the Q branch, because it is the strongest. They are not lines of P and R branches with a fortuitous phase relation to each other, for the weaker lines remain midway between the stronger ones for the whole observable length of the branch.

The existence of this alternation of intensities shows at once that the nuclear spin cannot be zero, as the failure to find hyperfine structure of the atomic lines was thought to indicate.

The exact value of the spin could be found from the ratio of alternate intensities by the accepted formula that this ratio is equal to $s/(s+1)$. Unfortunately our present measurements do not permit the quantitative determination of this ratio. It is probably safe to say, however, that it is not as pronounced as 1:3; i.e. that $s>\frac{1}{2}$. Probably $s=1,1\frac{1}{2}$ or 2, but this cannot be relied upon. We hope to measure the alternation of intensities at a future time.

Further evidence that alternate lines of the bands are not missing, and hence that the nuclear spin is not zero, can be obtained from a study of the spacing of the lines in the branches. If one assumes that the spin is not zero, and all lines are present, then the second differences of the frequencies of the lines in a branch should be very approximately equal to $2C$, where $C=B'-B''$ in the usual band spectrum notation. If the spin were zero and alternate lines were missing the second differences between the lines which appeared would be $8C$. The second differences observed are, for all the branches of all the bands studied, about -0.016 cm^{-1}, yielding $C=-0.008$ cm^{-1} on the first, and correct, assumption, or $C=-0.002$ on the second. Now we do not yet know the true C of the potassium molecule, but a comparison with the accurately known values for lithium and sodium (see Table I) is sufficient to

show that the value -0.002 cannot be correct, whereas -0.008 is a quite reasonable extrapolation.

A still more definite test would be to compare the extrapolated values of B' and B'', the two larger quantities of which C is the relatively small difference. Pending the result of a complete analysis of our plates, which we expect to publish later, B' and B'' can best be estimated as follows: Mecke has noticed that the quantity B_0/ω_0 does not change much during a transition, or in other words, that $B_0'\omega_0''/B_0''\omega_0'$ is usually approximately unity. In the case of lithium[10] it is 1.07. In sodium[9] it is 1.04. Let us extrapolate its value for potassium as 1.02 which should not be wrong by more than a few percent, and is certainly more than sufficiently accurate for our purpose. Now[11] $\omega_0''=92.64$ and $\omega_0'=74.73$ so that we find $B''_0/B'_0=1.21$. With this value for the ratio of the B's it is possible to calculate the values of the B's themselves which correspond to each of the above assumptions about C. The results are given in Table I.

TABLE I. *Values in parenthesis are estimates based on the extrapolation for* $B_0'\omega_0''/B_0''\omega_0'$.

	Li_2	Na_2	K_2(if $s>0$)	K_2(if $s=0$)
M	7	23	39	
$-C$	0.1162	0.0289	0.008	0.002
$-MC$	0.81	0.66	0.31	0.08
$B_0'\omega_0''/B_0''\omega_0'$	1.07	1.04	(1.02)	
B_0'	0.5532	0.1254	(0.038)	(0.0095)
B_0''	0.6694	0.1543	(0.046)	(0.0115)
MB_0'	3.87	2.88	(1.48)	(0.37)
MB_0''	4.69	3.55	(1.79)	(0.45)

It will be seen that the values deduced on the assumptions that $s>0$ and that all lines are present are plausible, while those deduced from the alternative assumption are not. This is particularly apparent in lines 4, 8 and 9 in which the constants have been multiplied by the atomic weight M.

We may say then, with considerable certainty, that the spin of the potassium nucleus (K^{39}) is not zero. And it is perhaps permissible to doubt the inferences, as to non-existence of nuclear spin, that have been drawn in other cases from failure to find hyperfine structure.

[10] Harvey and Jenkins, Phys. Rev. **35,** 789 (1930).
[11] Crane and Christy, Phys. Rev. **36,** 421 (1930).