## The Quadrupole Moments and Spins of BR, Cl, and N Nuclei

C. H. Townes, A. N. Holden, J. Bardeen, and F. R. Merritt
*Bell Telephone Laboratories, Murray Hill, New Jersey*
April 4, 1947

FREQUENCIES and relative intensities of absorption lines near 24,000 megacycles in gaseous BrCN and ClCN have already been reported.[1] These lines represent rotational transitions $J=2$ to $J=3$ for BrCN and $J=1$ to $J=2$ for ClCN, which are split into a hyperfine structure. It has also been pointed out that the main features of this splitting appear to be caused by nuclear quadrupole moments.[2]

More detailed analysis of the spectra yields information about nuclear moments of Br, Cl, and N are shown in Table I.

The spins of the bromine nuclei are in agreement with values given by Tolansky,[4] but spins for the chlorine nuclei found by this work do not agree with the previously determined[5] value of 5/2. The spin of $N^{14}$ is, of course, well known, and its quadrupole moment has been detected in the ammonia spectrum.[6] In the present case the coupling 3.66 Mc is not far different from the value 4.1 Mc for the ammonia molecule, and here we may determine the quadrupole sign, which could not be obtained previously. To determine the quadrupole sign for each nucleus, the sign of $\partial^2 V/\partial_z{}^2$ is assumed to be the same as that found in the hydrogen molecule.[7]

About one-third of the BrCN molecules are excited to the lowest vibrational (bending) mode at room temperature. Eight weak lines appear to be caused by these excited molecules, and in order to fit the observed positions of these eight lines, values must be assumed for the change in rotational constant with vibrational excitation and for $l$-type doubling. These values are consistent with what is known about such effects but cannot be exactly calculated. The rotational constant $B_0$ for the ground state is taken smaller by $B_0/340$ than $B_{(v_2=1)}$, the rotational constant for molecules excited to the first level of the bending vibrational mode. The $l$-type doubling, which is present in this excited state, gives a difference in the apparent value of $B_{(v_2=1)}$ for the two states of $B_{(v_2=1)}/1000$. Intensity ratios between two of the BrCN lines attributed to excited states and two lines attributed to the ground state were observed at +65°C and −40°C and found to change with temperature as expected by approximately a factor of two.

Agreement between experimental results previously

TABLE I. Data on nuclear quadrupole moments.

| Nucleus | Spin | Sign of quadrupole moment | Quadrupole coupling* in megacycles |
|---|---|---|---|
| $Br^{79}$ | 3/2 | positive | 720±10 |
| $Br^{81}$ | 3/2 | positive | 556±10 |
| $Cl^{35}$ | 3/2 | negative | 84±4 |
| $Cl^{37}$ | 3/2 | negative | 64±4 |
| $N^{14}$ | 1 | negative | 3.66±0.15 |

* Quadrupole coupling is defined as $(eQ)\partial^2 V/\partial_z{}^2$ where $Q$ is the nuclear quadrupole moment,[3] $V$ is the electric potential produced at the nucleus by the rest of the molecule, and $z$ is the coordinate along the molecular axis.

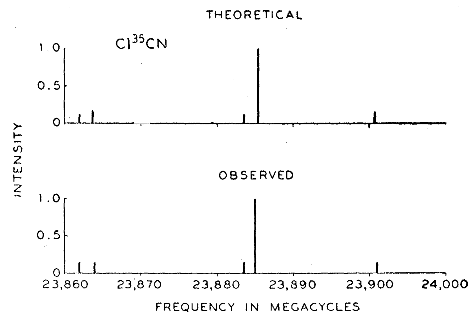


FIG. 1. Comparison of BrCN spectrum observed under low resolution with calculated pattern caused by Br quadrupole moment.

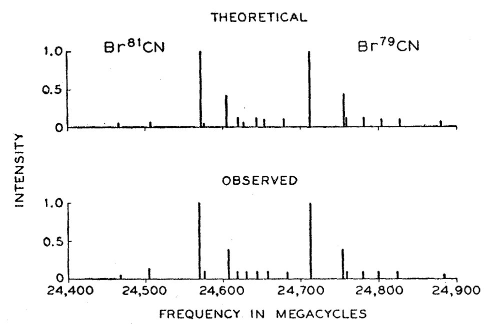


FIG. 2. Comparison of $Cl^{35}CN$ spectrum observed under low resolution with calculated pattern caused by Cl quadrupole moment.

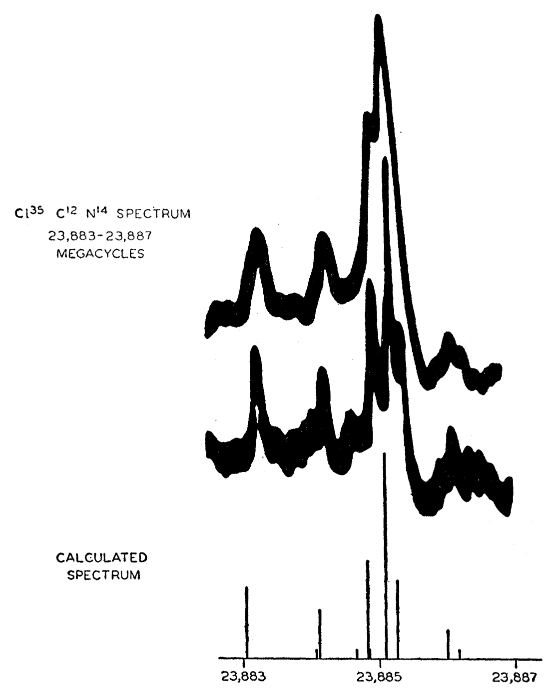


FIG. 3. Comparison of portion of $Cl^{35}CN$ spectrum under high resolution and spectrum calculated, including effects of both Cl and N quadrupole moments.

published and theoretical expectations[8] for BrCN is shown in Fig. 1, and for $Cl^{35}CN$ in Fig. 2, assuming quadrupole splitting caused by Br and Cl nuclei only. One of the lines shown for ClCN was not originally reported, since it had not at that time been resolved.

In order to detect the smaller splitting caused by nitrogen which was superimposed on the spectra of Figs. 1 and 2, it was necessary to increase the resolving power of the apparatus previously used. The oscilloscope trace of the two central lines of ClCN shown in Fig. 2 is displayed under high resolution[8] at two different pressures in Fig. 3. As a comparison, the theoretical splitting expected from $N^{14}$ is included in the figure. The weaker line of the central pair is not split at all by $N^{14}$ effects and is the lowest frequency component of this group. Other ClCN lines were observed under high resolution, and their splitting likewise agreed with expectations. The exact and detailed agreement between observations and theory leaves little doubt that the true value of the spins for the chlorine nuclei is 3/2 rather than 5/2.

Figure 3 gives an interesting indication of the high resolving power which can be obtained. Here, in spite of considerable difference in intensity, lines are resolved which are separated by only 140 kilocycles or $5\times10^{-6}$ cm$^{-1}$.


1 Townes, Holden, and Merritt, Phys. Rev. **71**, 64 (1947).
2 Townes, Holden, and Merritt, New York Meeting Am. Phys. Soc. paper X8.
3 Kellogg, Rabi, Ramsey, and Zacharias, Phys. Rev. **57**, 677 (1940).
4 Tolansky, Proc. Roy. Soc. **136**, 585 (1936).
5 Elliott, Proc. Roy. Soc. **127**, 638 (1930); Shrader, Phys. Rev. **64**, 57 (1943).
6 Dailey, Kyhl, Strandberg, Van Vleck, and Wilson, Phys. Rev. **70**, 984 (1946); Coles and Good, Phys. Rev. **70**, 979 (1946).
7 Nordsieck, Phys. Rev. **58**, 310 (1940).
8 Details of theory and of experimental methods for obtaining high resolution will be published later.


## Proposed Methods of Detecting the Neutrino


K. C. Wang

*Department of Physics, National Chekiang University, Hangchow, China*


March 24, 1947

It has been pointed out by the writer[1] and others that the experimental investigation of $K$-electron capture of $Be^7$ may give a relatively easy way of detecting the neutrino. Allen[2] has actually carried out such an experiment with a positive result. However, this cannot be regarded as a decisive proof of the existence of the neutrino because, as commented on by some authors,[3] the method is still subject to relatively large corrections. We here propose some new methods of attacking the problem.

Recent experiments of Baldwin and Klaiber[4] have shown that, with x-ray of nearly 100 Mev, nuclear reactions of the types $Z_A(\gamma,n)Z_{A-1}$ and $Z_A(\gamma,pn)(Z-1)_{A-2}$ can occur with rather large probabilities. It thus seems not too difficult to prepare the nucleus $B^{12}$ from $C^{13}$ or $N^{14}$. If a cloud chamber is filled with gases containing $C^{13}$ or $N^{14}$ and then exposed to a source of 100 Mev x-rays, $B^{12}$ will be produced in the chamber. Since $B^{12}$ has a very large beta-ray energy (12 Mev) and its mass is comparatively small, it may be much easier to detect and to measure the momentum of the recoil nucleus than in the case of $Cl^{38}$ (beta-ray energy 5 Mev) investigated by Crane and Halpern.[5] If, because of its too short lifetime (0.022 sec.), the investigation of the $B^{12}$ recoils as suggested above is found not to be practicable, we propose the use of $N^{16}$ from the reaction $O^{16}(n,p)N^{16}$. Let the cloud chamber be filled with oxygen; under the exposure to neutrons from a Li+D source, some $N^{16}$ nuclei may be formed in the chamber. The expansion of the chamber then follows immediately after the cutting off of the neutron source because the lifetime of $N^{16}$ is only 8 sec. So far as the observation of the recoil nuclei is concerned, $N^{16}$ is also more favorable than $Cl^{38}$ although not so favorable as $B^{12}$.

There is another method which may also prove valuable. Consider the nucleus $Na^{24}$ which after $\beta$-radiation also emits a $\gamma$-ray or the internally converted electron ($e^-$-radiation). According to Konopinski,[3] this $\gamma$-ray may have a high multipole character and therefore may have a rather long life (about $10^{-7}$ sec. for octupole radiation). Thus after the $\beta$-emission, some of the recoil nuclei will, if they are allowed to move freely by placing the source and accessories in a high vacuum, travel a distance of the order of one centimeter before the emission of the $\gamma$-radiation or the $e^-$-radiation. This fact can be utilized to detect the neutrino by applying either the cloud chamber or "directional $e^-$-coincidence counting" technique. By "directional coincidence" we mean that the relative positions of the counters, the source, and the slits are so arranged that coincidence counting can be produced only when the direction of the $\beta$-emission and that of the recoil nucleus, which subsequently emits an $e^-$-particle, make a certain definite angle $\theta$. If $\theta$ is always found to be 180°, it will be definite that no neutrino has been emitted during the $\beta$-disintegration. Otherwise, conservation principles can be used to find the energy and momentum of the neutrino, which can then be statistically checked with the Fermi theory. Even if $Na^{24}$ is not suitable for our purpose, it is very probable that, for certain $\beta\gamma$ (not $\gamma\beta$)-radiative substances, the $\gamma$-radiation lifetimes lie between $10^{-7}$ and $10^{-4}$ sec. For these substances, there will be a high probability of internal conversion, thus favoring this method. (It is of interest to note that by measuring the length of the recoil path, the lifetime of such $\gamma$-radiation can be determined.) Besides, certain fission fragments, which emit $\beta$-rays quickly and successively, may also be useful. Finally, the natural $\beta\alpha$-radioactive substance ThCC′ may also be considered although the recoil mass is, in this case, too large, and the troublesome "aggregate recoil" may occur. After all, the possibility of carrying out experiments like these depends on the preparation of a "monolayer" source, since scattering process would probably confuse the results.

A third method is to utilize the $K$-radioactive property of certain substances like $Be^7$, $Ca^{41}$, $Cr^{51}$, etc. For some of these nuclei the $K$-capture may be followed by $\gamma$-radiation of rather long lifetime. By placing the source in vacuum, the two isomeric forms can be separated and tested for recoil by $K$-capture. The success of this separation will unambiguously prove the existence of the neutrino.

It may be mentioned that the investigation of the neutrino would also be possible from the meson disintegra-