

FIG. 1. The integral-disintegration curves which should be obtained if negative mesotrons both disintegrate and get captured. The values $(1/\lambda)'$ are the "mean-life" value calculated from the average slope of these curves.

should still be observable in materials of suitable atomic number. This change of the disintegration constant is due to the fact that the experimental data obtained really represent a superposition of two decay curves, one produced by positive mesotrons with a mean life $1/\lambda$ and one produced by negative mesotrons with a mean life $1/(\lambda + \Lambda)$. Hence, the total disintegration curve is represented by the following expression:

$$N_d = N_0^+ \exp(-\lambda t) + N_0^- [\lambda / (\lambda + \Lambda)] \exp[-(\lambda + \Lambda)t].$$

Disintegration curves of this kind for values of Λ between 0 and ∞ , and assuming an equal number of positive and negative mesotrons, are shown in Fig. 1. The quantities $(1/\lambda)'$ are the "changed" values of the mean life obtained by determining the average slope of the curves for a time interval from 1×10^{-6} to 4.5×10^{-6} sec. This "change" may be as large as 11 percent. From the curves, however, it is clear that in such an investigation particular attention must be paid to very short decay times, especially if the capture constant is large. This consideration applies also to experiments where the ratio of disintegration electrons to stopped mesotrons is measured.

- ¹ M. Conversi, E. Pancini, and O. Piccioni, Phys. Rev. **71**, 209 (1947).
- ² T. Sigurgeirsson and A. Yamakawa, Phys. Rev. **71**, 319 (1947).
- ³ S. Tomonaga and G. Araki, Phys. Rev. **58**, 90 (1940).
- ⁴ E. Fermi, E. Teller, and V. Weisskopf, Phys. Rev. **71**, 314 (1947).
- ⁵ John A. Wheeler, Phys. Rev. **71**, 320 (1947).
- ⁶ N. Nereson and B. Rossi, Phys. Rev. **64**, 199 (1943).

Analysis of the Hyperfine Structure in the Microwave Spectrum of the Symmetric Top Molecule CH_3I^*

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THE preliminary measurements¹ of the $J=1$ to $J=2$ rotational transition of CH_3I have been repeated at a lower temperature, -70°C . As a result of the increased

absorption at the lower temperature, additional lines have been observed and a more accurate estimate of relative intensities has been made.¹ The measurements at low temperature revealed that none of the observed lines arises from molecules in excited vibrational states.

A complete analysis of the hyperfine structure resulting from the nuclear quadrupole moment of iodine has now been made. In Fig. 1 the theoretically predicted structure is compared with that experimentally observed.² The particular formula used to calculate the positions of the CH_3I lines is that used by Coles and Good³ to calculate the quadrupole effects in NH_3 :

$$T_F = [eQ\partial^2 V / \partial z^2] \cdot [3K^2 / 2J(J+1) - \frac{1}{2}] \cdot [3C(C+1) - 4J(J+1)I(I+1) / (2J-1)(2J+3)(2I-1)(2I+3)], \quad (1)$$

where

T_F represents the hyperfine splitting of the rotational energy levels,

$$C = F(F+1) - I(I+1) - J(J+1),$$

$$F = J+I, J+I-1, \dots, J-I \text{ (or to } I-J \text{ when } I \geq J),$$

$I = 5/2$, the nuclear spin of iodine, and

$eQ(\partial^2 V / \partial z^2)$ represents the quadrupole coupling coefficient, Q being the quadrupole moment of iodine, V , the molecular potential at the iodine nucleus, and z , the coordinate axis along the C-I bond.

Because of the nuclear effects the K -levels, associated with a given J -level, which otherwise would be degenerate for low J -values, are well separated. This allows two hyperfine patterns for the $J=1$ to $J=2$ transition corresponding to the transitions $0 \rightarrow 0$ and $1 \rightarrow 1$ for K . The relative intensities of the lines of a given K -transition can be determined from the intensity rules for atomic fine structure. To determine the relative intensities of the two

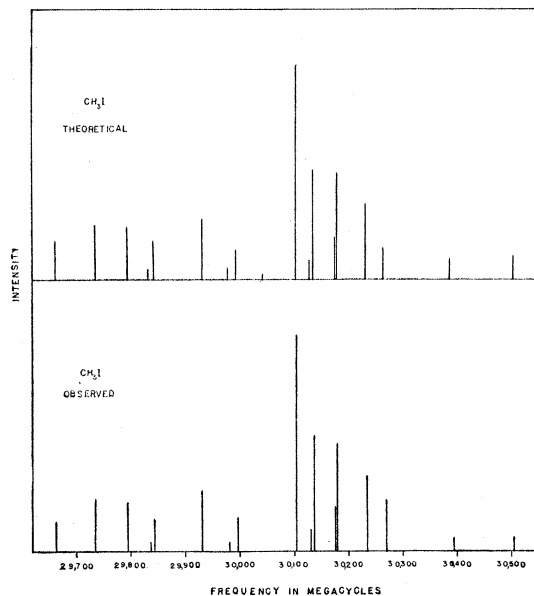


FIG. 1. Theoretical and observed hyperfine structure of the CH_3I spectrum for the rotational transition $J=1$ to $J=2$.

patterns arising from different K -transitions we have applied the theory of Dennison:⁴

$$\frac{\text{Intensity of terms for } K \text{ divisible by } 3}{\text{Intensity of terms for } K \text{ not divisible by } 3} = \frac{4I^2 + 4I + 3}{4I^2 + 4I}, \quad (2)$$

where I is the nuclear spin of the 3 identical nuclei. Here I is $\frac{1}{2}$ the spin of H; and the intensity ratio is 2:1.

It is apparent from the above analysis that the microwave spectra of symmetric top molecules can be used in two different ways to ascertain nuclear spins. From formula (1) the spin of iodine is determined as 5/2. Formula (2) allows a determination of the spins of the 3 identical atoms on the corners of the tetrahedron.

The quadrupole moment of the iodine nucleus is negative, in agreement with the accompanying ICN measurements. The value of the coupling coefficient $eQ(\partial^2 V/\partial z^2)$, 1520 ± 15 mc, for CH_3I is different from the ICN value, 2070 ± 20 mc. Since Q is the same, this means that the $\partial^2 V/\partial z^2$ factor is significantly different for the two cases and that the C—I bonds in the two molecules are not equivalent. The difference in bonding is also revealed by the widely differing C—I interatomic distances, 2.00 Å for ICN and 2.13 Å for CH_3I .

The moment of inertia, I_B , for the ground vibrational state determined from the hypothetical frequency corresponding to no quadrupole-moment splitting of the energy levels is 111.4×10^{-40} g cm.² The C—I interatomic distance remains 1.13 Å, as determined in the previous paper.

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¹ Walter Gordy, A. G. Smith, and James W. Simmons, *Phys. Rev.* **71**, 917(L) (1947), in the preliminary report a rather large error was made in the estimated intensity of one of the lines. This is corrected in Fig. 1.

² For references to the development of the theory of quadrupole-moment interactions see the accompanying note on BrCN and ICN.

³ D. K. Coles and W. E. Good, *Phys. Rev.* **70**, 979 (1946).

⁴ D. M. Dennison, *Rev. Mod. Phys.* **3**, 280 (1931); see also G. Herzberg, *Infrared and Raman Spectra of Polyatomic Molecules*, (D. Van Nostrand Company, Inc., New York, 1945), p. 28.

Proton-Proton Scattering at 10 Mev

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A STUDY has been made of R. R. Wilson's experimental results¹ in order to analyze the proton-proton interaction in the 3P state. We have found that the P -scattering is compatible with the assumption that the nuclear force in this state is given by a 10-Mev repulsive potential with a range of 2.5×10^{-13} cm.

We have compared Wilson's results with the general formulae for scattering with arbitrary phases of the S - and P -waves. The best value for the S -phase is $K_0 = 52^\circ 30'$. Although the cross sections found for angles less than 30° in the center of mass system are not sufficiently accurate to be used for numerical calculations, they definitely show that the P -phase is negative, implying a repulsive

TABLE I. Relation between P -wave phases and interaction potentials.

Potential	K_1 (calculated)	K_1 (perturbation theory)
-30 Mev	5.6°	2.7°
-20	3.0	1.8
-10	1.3	0.9
0	0.0	0.0
10	-0.8	-0.9
20	-1.3	-1.8
30	-1.8	-2.7

force. The value $K_1 = -0.8^\circ$ fits the experimental points best, though with the stated experimental errors this figure is an order of magnitude estimate only. Since Wilson states that the absolute values of the cross section are less reliable than their ratios, we have confirmed that, adjusting both K_0 and K_1 , a 10 percent change in scale changes K_1 only by about 0.2° .

From the S -phase it is possible to calculate for each energy the "relative slope" of the wave function (ratio of the derivative to the function itself) at the limit of the range of the nuclear forces. The derivative of this quantity with respect to energy is directly related to the mean range of forces, without any hypothesis about the shape of the well, and combining the results of Wilson and Creutz at 8 Mev² with those at 10 Mev and with previous values at smaller energies, we have obtained for the range of forces the value $2.4_8 \times 10^{-13}$ cm.

Assuming this range, one can calculate the P -phase shift as a function of the depth of a rectangular potential well (added to the Coulomb potential). The results are given in the second column of Table I.

Since the experimental value of K_1 is -0.8° , we see that the proton-proton interaction in the 3P state is represented by a repulsive potential of about 10 Mev. The measurements of scattering at 14.5 Mev⁴ do not disagree with this result.

Since this conclusion is at variance with the theoretical curve given in the graph in Wilson's note,¹ which indicates a P -phase of about -2.1° for a 10.5-Mev potential, we have checked our calculation by means of perturbation theory using Eq. (8.1) in the paper of Breit, Condon, and Present.³ This leads to the values in the third column of the table, which all seem to agree with the second column for small potential.

This result is quite compatible with current ideas about nuclear forces. If we assume, as is customary, that the forces are charge-independent and are mainly of the "Majorana" and "Heisenberg" type, we can estimate the depth of well for these two forces from the 3S and the virtual 1S level of the deuteron. With the value of the range used above, this leads to a repulsive potential of about 12 Mev for the 3P state, in quite satisfactory agreement with the present data. However, it is evidently quite possible to admit a certain amount of "Wigner" or "Bartlett" force and some tensor force.

¹ R. R. Wilson, *Phys. Rev.* **71**, 384 (1947).

² R. R. Wilson and E. C. Creutz, *Phys. Rev.* **71**, 339 (1947).

³ G. Breit, E. U. Condon, and R. D. Present, *Phys. Rev.* **50**, 825 (1936).

⁴ R. R. Wilson, E. J. Lofgren, J. R. Richardson, B. T. Wright, and R. S. Shankland, *Phys. Rev.* **71**, 560 (1947).