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 $eQ(\partial^2 V/\partial z^2)$, $1520 \pm 15^{\text{mc}}$, for $CH_3I$ is different from the ICN value, $2070 \pm 20$ 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, 2.00A for ICN and 2.13A 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 $111.4 \times 10^{-40}$ g cm.[2] The C−I interatomic distance remains 1.13A, 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 results[1] 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 $2.5 \times 10^{-13}$ 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 $K_0 = 52° 30'$. 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 force. The value $K_1 = -0.8°$ 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°.

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 |

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 Mev[2] 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 Mev[4] 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).