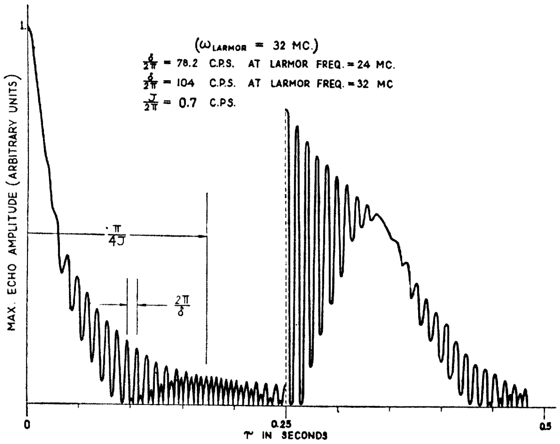

FIG. 2. Echo envelope plot for protons in dichloroacetaldehyde. The break in the plot at $\tau=0.25$ sec indicates continuation of the plot in the region of small echo amplitude, but multiplied by a factor in order to make the plot readable.

compared with experiment. Apart from explaining the shape of the echo envelope, its consistency with observations made by the slow passage method also remains to be established.

We are not prepared, at present, to propose a detailed mechanism which can explain the observed effects.[11] It is well known that the direct nuclear dipole-dipole coupling averages out completely due to the rapid and random rotations of a molecule in a liquid.[12] We wish to point out, however, that any anisotropy effects would prevent a complete averaging out of this coupling, and, for reasons of rotational invariance, could indeed be expected to lead to a Hamiltonian of the form (1).[13]

The authors are grateful to Professor F. Bloch for his valuable advice and suggestions. The authors are grateful to Gutowsky, McCall, and Slichter[3] for sending them a copy of their letter in advance of publication to which was later added (while in press) the suggestion, arrived at independently, that the J splitting depends on the interaction $\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2$. One of us (E. L. H.) wishes to thank the National Research Council for Fellowship support during the course of this research.

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* This research supported in part by the ONR. See accompanying letter on independent work by McNeil, Slichter, and Gutowsky.

† National ResearchCouncil Post doctoral Fellow.

[1] E. L. Hahn, Phys. Rev. **80**, 580 (1950).

[2] Arnold, Dharmatti, and Packard, J. Chem. Phys. **19**, 507 (1951).

[3] H. S. Gutowsky and D. W. McCall, Phys. Rev. **82**, 748 (1951); Gutowsky, McCall, and Slichter, Phys. Rev. **84**, 589 (1951).

[4] W. G. Proctor and F. C. Yu, Phys. Rev. **77**, 717 (1950).

[5] W. C. Dickinson, Phys. Rev. **77**, 736 (1950).

[6] For long relaxation times the echo method has the advantage of being able to resolve frequencies of the order of 1 cps even though the external field inhomogeneity over the sample produces a spread in Larmor frequencies much greater than this.

[7] J. T. Arnold and M. E. Packard, Phys. Rev. **83**, 210 (1951).

[8] The rapid transfer between possible structural isomers of $CHCl_2CHO$ causes an averaging into two definite chemical shifts, one for each proton. This will result when the lifetimes in each isomeric state (obtained from known chemical potential barriers) are much shorter than the period associated with the observed frequency difference between chemical shifts (104 cps at a Larmor frequency of 32 Mc).

[9] Because of electric quadrupole broadening, the magnetic moments of the Cl^{35}, Cl^{37} nuclei are assumed to be ineffective because their quantum states have lifetimes short compared to the relaxation time of the protons and $1/J$.

[10] In references 3 it is observed that the J splitting depends upon the statistical weights of possible orientations of nonequivalent neighbors and the magnitude of their magnet moments.

[11] The operator (1) is formally obtained if one considers that two nonequivalent protons mutually exchange positions in the molecule by quantum mechanical exchange. Because of mass considerations, the exchange hypothesis is excluded since F^{19} nuclei are observed to exhibit the J splitting as well as protons.

[12] Bloembergen, Pound, and Purcell, Phys. Rev. **73**, 679 (1948).

[13] As a possible source of anisotropy we have considered that caused by the electron configuration. Gutowsky, McCall, and Slichter have also suggested that a coupling takes place via the electrons (see reference 3). This would be similar to the pseudo-quadrupole effect for a single nucleus, discussed by H. M. Foley, Phys. Rev. **72**, 504 (1947). This effect is also related, in its origin, to Ramsey's proposal [N. F. Ramsey, Phys. Rev. **78**, 699 (1950)] for explaining chemical shifts. It seems, however, difficult to reconcile the orders of magnitude of J to be thus expected with the experimental values.

$\pi^- - p$ Scattering Observed in a Diffusion Cloud Chamber*

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SCATTERING of 60-Mev negative pions has been observed in a diffusion cloud chamber similar to one previously mentioned,[1] operated in a pion beam at the Columbia University Nevis cyclotron.† The diffusion chamber shown in Fig. 1 was operated with 21 atmos of hydrogen and methanol vapor filling, bottom temperature −65°C and top +20°C. The track-sensitive layer was about 6 cm deep, starting at the bottom. The cyclotron ion source was pulsed every 4 to 6 sec so as to produce about 20 tracks which were photographed stereoscopically. Between pulses a clearing potential of about 1000V was applied while tracks settled out and vapor was replenished.

5600 pictures taken during the first day's operation have been examined. Since the pion beam contains some electrons and μ-mesons,[2] the pion path length was estimated from the fact that 642 $\pi-\mu$ decays in flight were observed with projected $\pi-\mu$ angles $>4°$ in one view. A correction of 30 percent must be applied to obtain the total number of $\pi-\mu$ decays of all angles. From the pion lifetime of 0.029 μsec,[2] pion energy, and hydrogen density, one can calculate that there is one $\pi-\mu$ decay per 2.0 g/cm² of hydrogen traversed, so that the total path length observed is 1670 g/cm².

From the angles, densities of ionization, ranges, and lack of multiple scattering of the tracks involved, $\pi^- - p$ scattering events can be identified with fair certainty. Among beam tracks scatterings of a few degrees that could be identified as electron-electron collisions were fairly numerous, but only three cases have been observed which can be considered to be $\pi^- - p$ scatterings, of which one is doubtful. The three events are very similar in appearance to the one shown in Fig. 2. The angles, measured from the incident pion direction, are: pion 54° and recoil proton 57° in the first case (Fig. 2); pion 70° and proton 44° in the second; pion leaves illuminated region and proton 35° in the third. It is not likely that scattering events were missed in scanning because the heavily ionizing recoil proton makes them more obvious than $\pi-\mu$ decays, and independent repeated scanning indicated an efficiency for observing $\pi-\mu$ decays of about 80 percent.

These data give a cross section of 3 millibarns for the scattering of 60-Mev negative pions by hydrogen, with a large statistical uncertainty. Chedester *et al.* have given a value of 13 millibarns

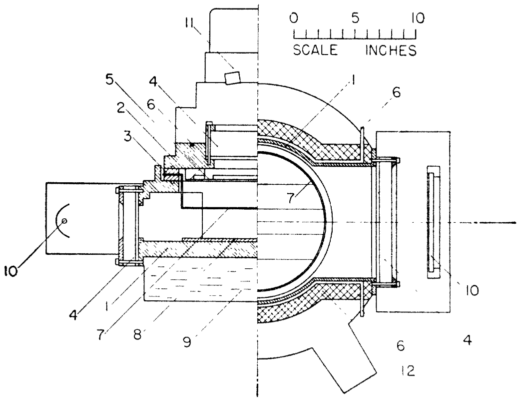

FIG. 1. Diagram of a high pressure diffusion chamber: chamber vessel (1), bottom plate and top flange cold-rolled steel, side walls $\frac{1}{4}$-in. stainless steel, velvet lined; top plate (2), cold-rolled steel; Bakelite ring (3), for thermal insulation; windows (4), inside $\frac{1}{4}$-in. "Allite" to withstand alcohol, outside "Plexiglas"; two concentric alcohol troughs (5), $\frac{1}{16}$-in. copper in thermal contact with (2); heater wires (6); sweeping field wires (7); black "Cararra" glass plate (8); dry ice—alcohol pan (9); light sources (10); stereoscopic camera (11); thermal insulation (12).

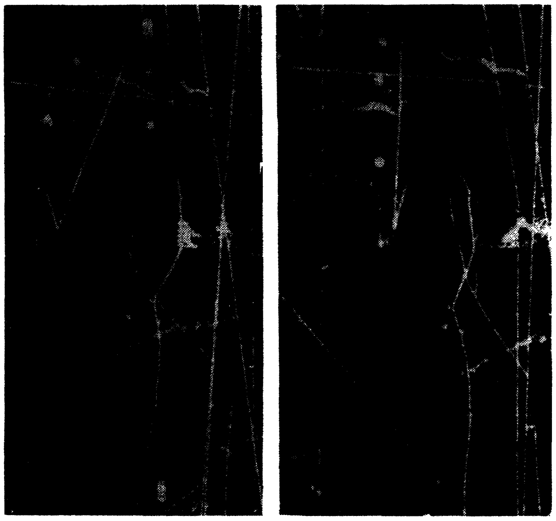

FIG. 2. Photograph of $\pi^- - p$ scattering. Event could be electron-proton scattering, but electron intensity is relatively small and Coulomb scattering through a large angle is extremely improbable.

for negative pions of 85 Mev.[3] The difference may be due to the difference in energy, or possibly to "charge exchange" scattering which would be missed in our experiment, or simply to our poor statistics. Our result agrees with a value of 2 to 4 mb calculated by Bethe and Wilson.[4]

We are indebted to the Nevis cyclotron staff for the opportunity to operate there and for the generous cooperation of members of the staff and operating crew. Many members at this laboratory contributed to this work, especially H. Marshak, R. Walker, and V. P. Kenney who have scanned many of the pictures.

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* Work performed at the Brookhaven National Laboratory, Upton, New York, under the auspices of the AEC.

[1] Miller, Fowler, and Shutt, Rev. Sci. Instr. **22**, 280 (1951).

† Supported jointly by the ONR and AEC

[2] Lederman, Booth, Byfield, and Kessler, Phys. Rev. **83**, 685 (1951).

[3] Chedester, Isaacs, Sachs, and Steinberger, Phys. Rev. **82**, 958 (1951).

[4] H. A. Bethe and R. R. Wilson, Phys. Rev. **83**, 690 (1951).

Satellite Pulses from Photomultipliers*

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(Received October 22, 1951)

IN the course of an experiment on μ-meson decay,[1] it was observed that the pulse from a scintillation counter was frequently followed within about one microsecond by one or more pulses, usually smaller than the first pulse, and that the frequency of these secondary pulses greatly exceeded the known rate of random noise pulses. Let us call the pulse which triggers the counting device the main pulse, and the secondary ones satellite pulses. The object of the investigation reported here was to find information which might be useful in devising methods of preventing satellite pulses from interfering with scintillation counting experiments. Three specific items of information were sought: the source of the satellites, their distribution in time after the main pulse, and how their frequency of occurrence depends on the voltage applied to the photomultiplier.

TABLE I. Comparison of noise and scintillation satellites.

Type of main pulse	Scintillation	Noise
Number of main pulses	140	129
Gross number of satellites	154	144
Estimated number of satellites due to random noise	30	10
Net number of satellites	124	134
Number of satellites per main pulse	0.89 ± 0.08	1.04 ± 0.09

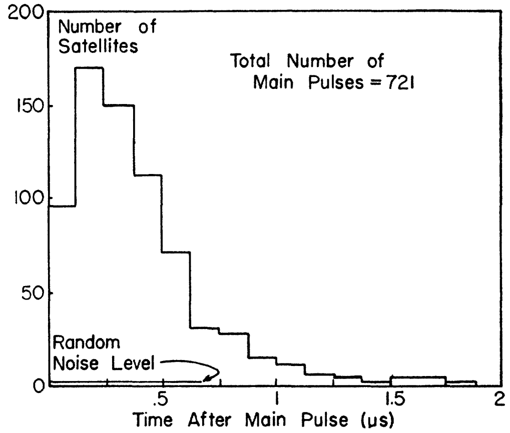

FIG. 1. Time distribution of satellites following scintillation pulses. The number of pulses shown in the first $\frac{1}{8}$-μsec channel is unreliable because there the presence of the main pulse made the search for small pulses difficult.

In order to determine whether the satellites originate in the scintillator or in the photomultiplier, we took first a group of oscilloscope pictures in which the main pulse was known to be a scintillation pulse, and secondly, a group of pictures in which the main pulse was a noise pulse. The pulses from a 1P21 photomultiplier looking into a cell with a terphenyltoluene solution were sent through distributed amplifiers, and displayed on an oscilloscope trace. Scintillations in the solution were detected by using coincidences with an auxiliary photomultiplier to trigger the oscilloscope. When noise pulses were being studied, the cell was removed, and the oscilloscope was triggered directly by the photomultiplier pulses. The traces were photographed, and then searched for satellites, the smallest pulse accepted being 1/30 of the minimum main pulse size. To make sure that the effect studied did not arise in the amplifier or oscilloscope, we verified that fast artificial pulses did not give satellites. In addition, satellites were observed with setups involving several different amplifiers and oscilloscopes. Twelve photomultipliers, including both 1P21's and 5819's, were examined, and all showed satellites.

Table I gives the results of the analysis of the two groups of pictures taken to determine the source of the sattelites. The photomultiplier was run at 1100 volts. The errors quoted are statistical. The distributions in time of the satellites after the main pulses were similar in the two cases. After 1.5 μsec the curves were essentially flat; so the random noise rate in Table I was computed by counting the number of pulses on the last 4 μsec of the trace.

The fact that there are the same number of satellites per main pulse, within the statistical error, whether the main pulse comes

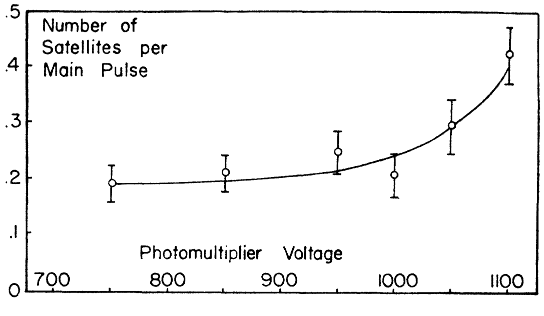

FIG. 2. Variation of satellite rate with photomultiplier voltage. The ordinate gives the number of satellites per trace greater than 1/15 of the minimum main pulse size.

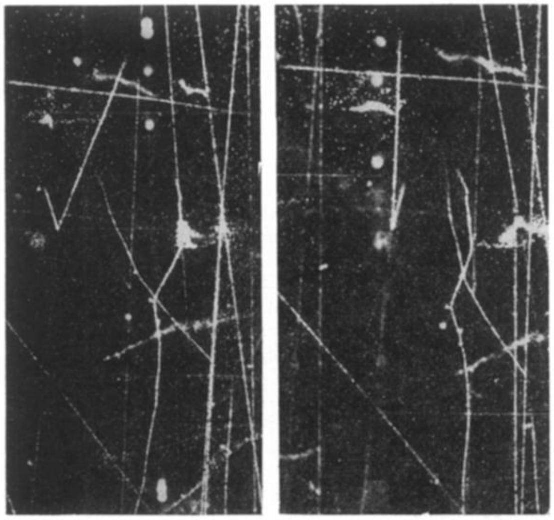

FIG. 2. Photograph of $\pi^- - p$ scattering. Event could be electron-proton scattering, but electron intensity is relatively small and Coulomb scattering through a large angle is extremely improbable.