Furthermore it was found that Rb^{91} has an isomeric state. Both these states of Rb^{91} (half-lives 100 sec and 14 min, respectively) decay to the well-known Sr^{91} 9.7 hr which again decays to the 60-day and the 50-min isomers of Y^{91}. All these radioactivities were found in the samples of mass number 91.

A more detailed account of the experiments will be published elsewhere.[2]

We wish to thank Professor N. Bohr for his interest taken in our work and Dr. J. Koch for help and advice during this investigation.

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The Nuclear Magnetic Moment of I^{129}

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THE nuclear resonance of long-lived radioactive I^{129} has been observed in a nuclear induction apparatus of the type originated by F. Bloch and similar to that recently described by Proctor.[1] The sample contained 33 mg of total iodine, as iodide, in a hydrazine solution. The iodine was isolated from fission products by one of the authors (G. H.). The I^{129} content was estimated to be 80 percent, the remainder being stable I^{127}. Heavy water was added to the solution, and all frequency ratio measurements were relative to deuterium. No magnetic catalyst was added. Frequency measurements were made with a Signal Corps type BC-221 frequency meter calibrated with harmonics from an external 100 kc, crystal-controlled oscillator which in turn was compared with WWV at 10 Mc. Frequency measurements made at nominal fields of 9500 and 12,200 gauss gave

$$\nu(I^{129})/\nu(D)=0.86744\pm0.0001.$$

Measurements were also made on I^{127}, but, since the resonance was weak in the original sample, a separate, chemically similar solution was used with a larger amount of I^{127} added. Measurements at nominal fields of 7500 and 9300 gauss gave

$$\nu(I^{127})/\nu(D)=1.30337\pm0.0002.$$

Measurements on I^{127} were also made in a sodium iodide solution and were not significantly different from the above.

Using Levinthal's[2] deuteron-to-proton frequency ratio of 0.1535059, the above ratios yield the following frequency ratios relative to the proton:

$$\nu(I^{129})/\nu(H)=0.13316$$
$$\nu(I^{127})/\nu(H)=0.20007_5.$$

With an iodine diamagnetic correction of 0.545 percent,[3] a spin of 7/2 for I^{129} [4] and 5/2 for I^{127},[5] and a value of 2.79268 nuclear magnetons[6] for the proton moment, these ratios give the following values of nuclear magnetic moments, in units of the nuclear magneton

$$\mu(I^{129})=+2.6173\pm0.0003$$
$$\mu(I^{127})=+2.8090\pm0.0004$$
$$\mu(I^{127})/\mu(I^{129})=1.0732.$$

The indicated estimated accuracy of the above values does not include the uncertainty in the diamagnetic correction. The sign of the I^{129} magnetic moment was obtained by comparison with I^{127} and D which are known to be positive.[1]

A previous measurement[7] of the nuclear magnetic moment of I^{129} made by microwave spectroscopy gave 2.74 ± 0.14 nuclear magnetons, which is consistent with the above value. The I^{127} results can conveniently be compared with published data in terms of the ratio of the I^{127} frequency to the proton frequency. Pound's[8] ratio for I^{127} relative to Na^{23}, 0.75664 ± 0.0002, has been converted to the ratio relative to the proton by using Bitter's[9] Na^{23}-to-proton ratio of 0.26450 ± 0.000026. This ratio and the ratio relative to the proton determined by Zimmerman and Williams[10] are compared below with the ratio obtained in this work.

$\nu(I^{127})/\nu(H)$	
0.20013 ± 0.00005	Pound
0.20003 ± 0.00007	Zimmerman and Williams
$0.20007_5\pm0.00003$	This work.

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‡ Work performed under contract with the AEC.

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Evidence Concerning the Reaction $p+p\rightarrow\pi^{+}+d$*

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THE mesons produced by protons on protons have been reported[1,2] by various observers. The strong forward high energy peak in the cross section found in the early work indicated that a deuteron may be produced in the reaction. The shape of the peak and the energetics of the reaction have given further evidence that this is the case.[3,4]

We have observed the reaction $p+p\rightarrow\pi^{+}+d$ by coincidence counting technique. By using a magnetic field to determine the momentum of the particles and finding the range of both in aluminum, we have essentially identified the reaction products by measuring the masses of both the meson and deuteron.

The arrangement is shown in Fig. 1. The 340-Mev external proton beam of the Berkeley cyclotron strikes a 1-inch thick polyethylene target. Typical trajectories are shown for the meson and deuteron in the forward direction. The orbits were located by using a wire with known current and tension. Each counter

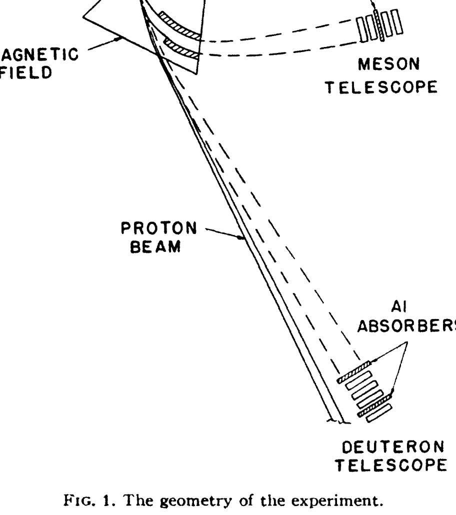

FIG. 1. The geometry of the experiment.

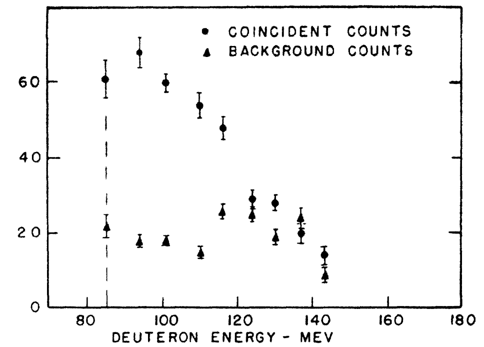

FIG. 2. The integral range spectrum of meson-deuteron coincidence counts as a function of deuteron energy. Probable errors are shown.

telescope consists of four liquid scintillators, $4\times5\times\frac{3}{4}$ inches in size, viewed by photo-multipliers. The outputs were mixed, using conventional electronics. The events recorded require both particles to have range large enough to enter the third counter of each telescope but to stop before the fourth. Range was varied with absorbers in the position shown. The integral range spectrum for the coincident events is shown as a function of range in the deuteron telescope in Fig. 2. The slope of the spectrum between 110 and 130 Mev corresponds to the variation of measured deuteron energy for production at various target depths owing to its energy loss in passing through the rest of the target. Protons from the reaction $p+p\rightarrow\pi^{+}+n+p$ of approximately the same velocity as the deuteron would not appear at ranges greater than the deuteron range of 90 Mev. The lowest energy point on Fig. 2 corresponds to zero absorber.

The momentum of the deuteron was measured by shifting the position of the deuteron telescope (see Fig. 3). Deuterons produced at the front and back of the target are expected to have momenta 630 and 710 Mev/c, respectively. The cone of the coincident deuterons was defined by the meson telescope to be $\sim2\frac{1}{2}$ inches in diameter. Protons from the reaction $p+p\rightarrow\pi^{+}+p+n$, for which we would have detected the meson, would appear at a maximum momentum of about 450 Mev/c (~12 inches from the center of the deuteron telescope). The main proton beam appears at 855 Mev/c (8.5 inches from the deuteron telescope). The deuteron mass calculated from these data is $2.2^{+0.6}_{-0.4}$ proton

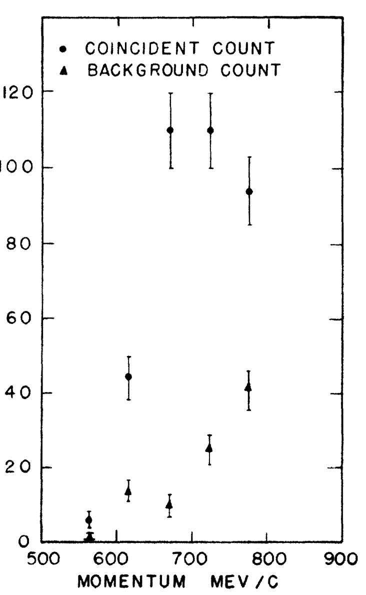

FIG. 3. Meson-deuteron coincidence counts as a function of deuteron momentum. Probable errors are shown.

TABLE I. Typical data taken with same geometry and beam intensity for equivalent number of protons. Probable errors are given.

Target	Meson counts	Coincidence counts	Background	Difference	Meson deuteron coincidences / Meson counts
Polyethylene	1085±18	144±7	46±4	98±8	—
Carbon	288±11	3±1	6±2	−3±2	−0.010±0.007
Hydrogen (Equivalent)	797±31	141±7	40±4	101±8	+0.127±0.010

masses. The meson mass was obtained by varying the magnetic field and measuring the range spectrum in the meson telescope. We obtain 270^{+80}_{-90} electron masses. The errors in the masses correspond to the limits of uncertainties in the momentum and range resolution of the deuteron and meson telescopes.

Mesons produced by 340-Mev protons on carbon in the same solid angle do not appear to be accompanied by correlated deuterons (see Table I). The meson telescope counts are approximately 90 percent mesons, and our high background appears to be accidental coincidences between the meson-deuteron events and the excessive singles rates of the final deuteron telescope counters.

Measurements of the absolute cross section are in progress.

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On the $\gamma-\gamma$-Correlation with Higher Multipoles

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RECENT experiments on $\gamma-\gamma$-angular correlations,[1] in particular the observed correlation[2] in the long-lived isomer Pb^{204}, have emphasized the need to extend the angular correlation calculations to higher multipoles. Thus far the only published tables of $\gamma-\gamma$-correlations are those of Hamilton,[3] but these are applicable only to successive nuclear transitions in which the γ-rays are either dipole or quadrupole. The extension of these tables using the method of Hamilton, although straightforward in principle, has thus far not been attempted because the amount of calculation required increases rapidly with the higher multipoles.

In this note we remark on several alternative methods of calculation which considerably simplify the problem of obtaining $W(\vartheta)$ for higher angular momenta. We first give specific results for some of the simpler cases of interest, and then indicate a general method for obtaining more complete tabulations:

(i) Instead of calculating $W(\vartheta)$ for all possible transitions consistent with the angular momentum selection rules for *fixed* multipole orders of the γ-rays, as Hamilton[3] has done, one can fix the multipole order of one of the γ-rays, say, the second, and the spins of the intermediate and final nuclear states, and vary the multipole order and spin of the initial state. This method is particularly simple when the final state has spin zero. For example, for transitions of the type:

$$\text{IA:}\quad L+1\xrightarrow{2^L}1\xrightarrow{2^1}0$$