TABLE I. Results for (γ, n) reactions in O^{16} and N^{14}.

	O^{16}	N^{14}
Peak (Mev)	24.2	24.2
σ_{max}(millibarns)	11.4	2.84
Integrated cross section to peak position (Mev-barns)	0.0312	0.015

a sharp increase at about 20 Mev, which may be the result of this effect.

In Fig. 1 is shown the saturated specific activity curve for N^{14}. The neutron yield at 22 Mev as determined from this curve is 2.38×10^4 neutrons/mole/r, which is lower than the value 6.5×10^4 obtained by Price and Kerst.[3] A curve drawn through the experimental points shows a small hump in the initial portion of this activity curve. Because of this unexpected behavior, dicyandiamide was irradiated. The nitrogen activity points obtained using it are shown in Fig. 1 as solid squares; they are in agreement with the previous results.

The resulting cross section curve for N^{14} (Fig. 2) shows a small peak at about 13 Mev as well as the larger one at 24.2 Mev. The falling off of the cross section curve immediately above 13 Mev, forming an apparent peak, may be caused by a (γ, np) reaction in N^{14}. The calculated threshold for this reaction, 12.5 Mev, is indicated in Fig. 2. In this process the neutron, presumed to be emitted first, leaves the N^{13} nucleus in a highly excited state from which it decays by proton emission rather than by gamma-emission. The product nucleus is C^{12} which is stable and therefore not detected in our experiment. While this process is not a true competition it has the effect of reducing the apparent (γ, n) yield when this is measured by detecting the radioactivity of the product nucleus (in this case N^{13}). Such processes have been called "cascade processes" by Katz and Cameron.[6] Another mechanism is required to explain why the (γ, n) cross section increases again above 17 Mev. Presumably this could be the result of the strong electric dipole absorption discussed earlier. Even for this portion of the curve it is probable that the cascade (γ, np) competition strongly reduces the measured (γ, n) yield leading to a smaller peak cross section in N^{14} (2.8 mb) than, for instance, in O^{16} (11.4 mb). This explanation requires a much larger (γ, np) cross section in N^{14} than in O^{16}. Evidence for this is amply provided by Gaerttner and Yeater[7] who observed that the (γ, np) reaction in N^{14} is almost 5 times that in O^{16} for 100 Mev-bremsstrahlung. Further, the threshold for the (γ, np) activity in O^{16} occurs much higher (22.9 Mev) and thus a cascade process in oxygen would have a much smaller effect on the (γ, n) cross section.

The information from the oxygen and nitrogen cross section curves is shown in Table I. No attempt has been made to estimate the width at half-maximum. The ratio of the oxygen and nitrogen integrated (γ, n) cross sections up to their peak positions is 2.08. In comparison the ratio of the total integrated cross sections obtained by Perlman and Friedlander[8] is 2.4 for 50-Mev and 2.2 for 100-Mev bremsstrahlung. The value obtained by Gaerttner and Yeater[7] is 1.9 for x-rays of maximum energy 100 Mev. It is seen that our results are in good agreement with those of the aforementioned authors as far as the ratios go.

The authors wish to thank Mr. L. B. Robinson for his assistance with many of the measurements involved. This work is supported by grants from the National Research Council and the National Cancer Institute of Canada.

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π^+-Meson Production Cross Section as a Function of Atomic Number

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THE relative cross sections for the production of 53±4-Mev mesons at 0°±7° by 340-Mev protons have been measured for C, Al, Fe, Cu, Ag, and Pb. The mesons were produced by the external scattered beam of the 184-inch synchrocyclotron. In order to separate the mesons from the proton beam, the mesons were turned through approximately 90° by means of a magnetic field[1] (Fig. 1). The mesons were detected by trans-stilbene crystals and electronic circuits already reported.[2] Briefly, a coincidence of the pulses caused by a π^+-meson passing through one crystal and stopping in a second generates a delayed gate which is put in coincidence with the μ^+ pulse resulting from the decay of the stopped π^+-meson.

Figure 2 shows the measured relative cross sections. The standard deviations indicated include only the statistical deviations

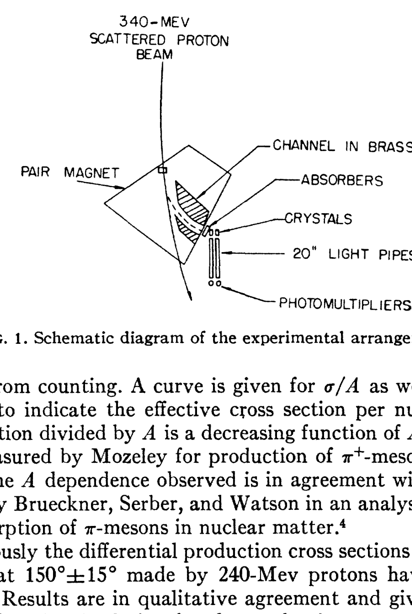

FIG. 1. Schematic diagram of the experimental arrangement.

arising from counting. A curve is given for σ/A as well as σ per nucleus to indicate the effective cross section per nucleon. The cross section divided by A is a decreasing function of A similar to that measured by Mozeley for production of π^+-mesons by photons.[3] The A dependence observed is in agreement with that obtained by Brueckner, Serber, and Watson in an analysis based on the absorption of π-mesons in nuclear matter.[4]

Previously the differential production cross sections for 20-Mev mesons at 150°±15° made by 240-Mev protons have been reported.[5] Results are in qualitative agreement and give the same general functional relation for the production cross section as a function of A.

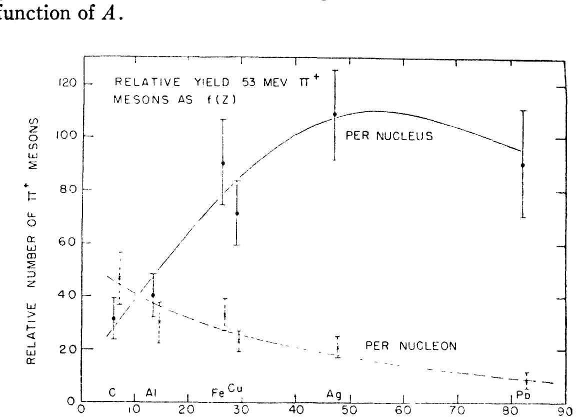

FIG. 2. The relative cross sections in arbitrary units for the production at 0°±7° of 53-Mev π^+-mesons by 340-Mev protons on C, Al, Fe, Cu, Ag, and Pb. The relative cross sections per nucleus are shown in solid lines and the relative cross section σ/A is shown in dotted lines.

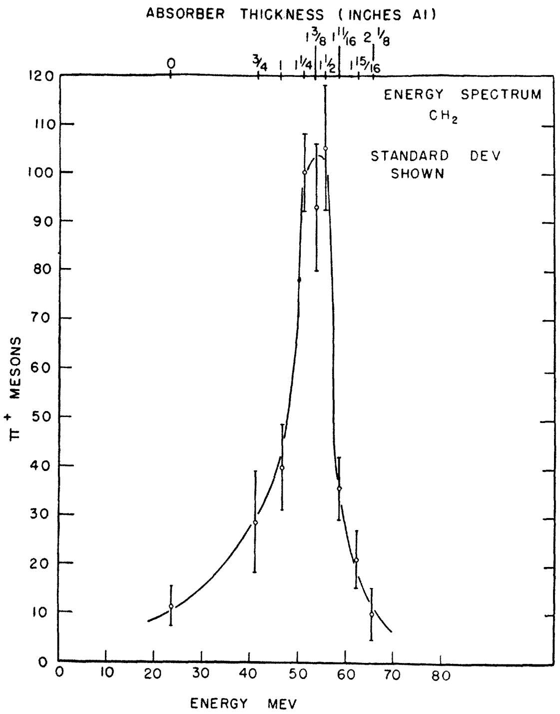

FIG. 3. A curve showing the π^+-meson energy distribution from a 2-inch polyethylene target bombarded by 340-Mev protons. Measurements were made at $0°\pm7°$ to the proton beam direction. Standard deviations are shown.

In order to compare counter detection of π^+-meson with plate techniques, the peak spectrum for the reaction $p+p<d+\pi^+$ was investigated. This spectrum has been investigated previously by plates.[1] Figure 3 shows the spectrum which was obtained with a 2-inch polyethylene target. The peak occurs at the energy expected from the thick production target which was used. The peak obtained by counters is considerably broader than that obtained by plates because of the greater energy width of the crystal detectors.

Thanks are due Professor C. Richman and co-workers for assistance in all parts of the experiment. We also wish to thank Professor O. Chamberlain for helpful discussions concerning the experiment.

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The Positronium Fine Structure*,†

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EXPERIMENTAL work now in progress at this laboratory,[1] and elsewhere,[2] on the fine structure splitting between the ^3S and S^1 ground states of positronium make it desirable to study in detail the properties of positronium predicted by the present theory of the electron. The fine structure of the energy levels has been worked out by Pirenne[3] and by Berestetski,[4] apparently independently. With the aim of proceeding to the next higher order (radiative corrections), we have first redone the calculations of these authors, and have found slight errors in both papers. Making the necessary changes in their work is a trivial matter. When this is done, one finds the shifts in energy, ΔE, of the singlet and triplet levels from the nonrelativistic values of $-mc^2\alpha^2/4n^2$ to be

$$\Delta E_{n,l}{}^s=\frac{11mc^2\alpha^4}{64n^4}+\frac{mc^2\alpha^4}{n^3}\epsilon_l{}^s;\quad \Delta E_{n,l,j}{}^t=\frac{11mc^2\alpha^4}{64n^4}+\frac{mc^2\alpha^4}{n^3}\epsilon_{l,j}{}^t,$$

where $\epsilon_l{}^s$, and $\epsilon_{l,j}{}^t$ are given by

$$\epsilon_l{}^s=-\frac{1}{2}\frac{1}{2l+1};\quad \epsilon_{l,j}{}^t=\epsilon_l{}^s+\delta_{0l}+\frac{(1-\delta_{0l})}{8(l+\frac{1}{2})}\times\begin{cases}\dfrac{3l+4}{(l+1)(2l+3)}, & j=l+1\\[2mm] -\dfrac{1}{l(l+1)}, & j=l\\[2mm] -\dfrac{3l-1}{l(2l-1)}, & j=l-1\end{cases}$$

(mc^2 is the rest energy of the electron and α the fine structure constant). Since the splittings depend on the principal quantum number, n, only through the factor $mc^2\alpha^4/n^3$, it is possible to study the "intrinsic fine structure" of the quantities $\epsilon_l{}^s$ and $\epsilon_{l,j}{}^t$, independent of any particular value of n. $\epsilon_l{}^s$ and $\epsilon_{l,j}{}^t$ are given numerically and represented schematically in Table I and Fig. 1. One finds the energy levels by adding the common shift, $0.1719/n^3$ and multiplying by $mc^2\alpha^4/n^3=11.6\ \text{cm}^{-1}/n^3=3.50\times10^5$ Mc/n, $=1.45\times10^{-3}$ ev/n^3 (in terms of inverse centimeters, megacycles, or electron volts, respectively). We find the Lamb shift in positronium to be about one-half the corresponding shift in hydrogen

TABLE I. Numerical values of intrinsic positronium fine structure.

	$-\epsilon_l{}^s$ and $-\epsilon_{l,j}{}^t$ for six values of l: 0	1	2	3	4	5
$-\epsilon_l{}^s$	0.5000	0.1667	0.1000	0.0714	0.0555	0.0454
$-\epsilon_{l,l+1}{}^t$	−0.0833	0.1083	0.0762	0.0585	0.0474	0.0399
$-\epsilon_{l,l}{}^t$	X	0.2084	0.1083	0.0744	0.0569	0.0462
$-\epsilon_{l,l-1}{}^t$	X	0.3334	0.1417	0.0904	0.0664	0.0525

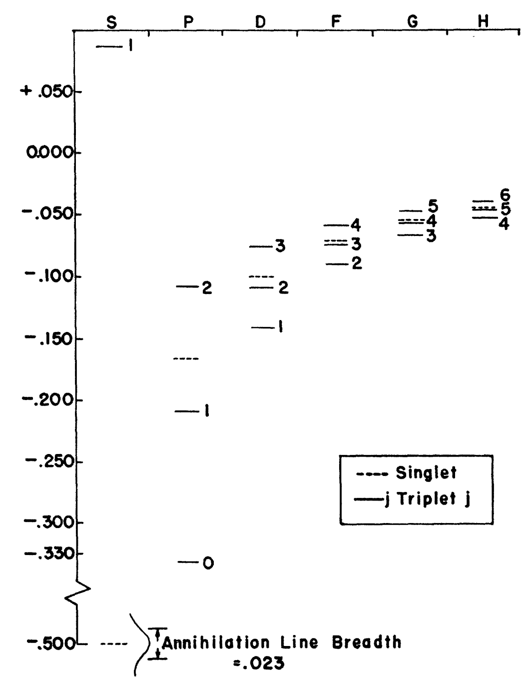

FIG. 1. Intrinsic positronium fine structure. To find energy levels, add $0.1719/n$ and multiply by $m\alpha^4/n^3=11.6\ \text{cm}^{-1}/n^3=3.50\times10^5$ Mc/n^3 $=1.45\times10^{-3}$ ev/n^3.