$h\nu = \Delta E$ is saturated. Nuclear electric quadrupole splitting of a second nuclear species with $I=1$ could be substituted for the electronic system, if ΔE were large enough to be useful.

I am indebted to Professor F. Bloch for helpful discussions.

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Nuclear Scattering of Gamma Rays below Meson Threshold*

G. E. Pugh,† D. H. Frisch, and R. Gomez
Department of Physics and Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts
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USING an energy-sensitive gamma-ray detector (which will be described soon in an article for the *Review of Scientific Instruments*) we have made preliminary measurements, at 90° and 135°, of the absolute gamma-ray scattering cross section for Be, C, Al, Cu, Sn, Pb, and Bi in the energy range from 35 to 130 Mev. The work was done in the bremsstrahlung beam of the M.I.T. synchrotron using targets about $\frac{1}{4}$ radiation length thick. The maximum beam energy was kept just below meson threshold to prevent confusion with decay gamma rays from the π^0 meson.

A standard coincidence, anticoincidence telescope with a lead converter was used to identify the gamma ray. The telescope was followed by a very large liquid scintillator which integrates the energy loss of the electron pair in its volume and thus estimates the energy of the gamma ray. The pulse height response of the counter to monoenergetic events, ranging from 25 to 150 Mev, was measured using electrons of known energy to simulate gamma rays (note the family of curves in Fig. 1A).

By using the known bremsstrahlung spectrum of the synchrotron, the efficiency of the converter, and the measured response of the counter to any energy event, it is possible to predict the response of the counter for any arbitrary scattering cross section.

In exact analogy with atomic x-ray scattering, the differential cross section was taken as: $d\sigma/d\Omega = \sigma^0[Z^2f^2 + (1-f^2)Z]$, where σ^0 is the individual-particle cross section and f is the nuclear analog of the atomic structure factor given by

$$f = \int_0^\infty \frac{\sin kr}{kr} 4\pi r^2 \frac{\rho(r)}{Z} dr.$$

Response curves were computed for a uniform distribution $[\rho(r) = \text{const}]$ of protons in nuclei of radii $R = R_0 A^{\frac{1}{3}} \times 10^{-13}$ cm. In Fig. 1 the curves (a) $R_0 = 0.8$, (b) $R_0 = 1.1$, (c) $R_0 = 1.4$ were obtained by using for σ^0 the classical Thompson individual-proton cross section:

$$\sigma_p{}^0(\text{Thompson}) = \tfrac{1}{2}(e^2/mc^2)^2(1+\cos^2\theta).$$

For elements heavier than aluminum the agreement with this classical Thompson scattering is as good as the statistics of the experiments. The results point to $R_0 = 1.1 \pm 0.2$.

In the lighter elements there is a clear disagreement which corresponds to too large a backward scattering of high-energy photons. Careful analysis of the data on Be and C enables us to deduce an experimental σ^0 which gives a best fit to the data, when R_0 is taken as 1.1. The ratio of this $\sigma_{(n+p)}{}^0$ "obs" to $\sigma_p{}^0$ Thompson together with a rough estimate of its statistical band of error is plotted in Fig. 2. The statistics are far from conclusive, but the trend of the data suggests that the

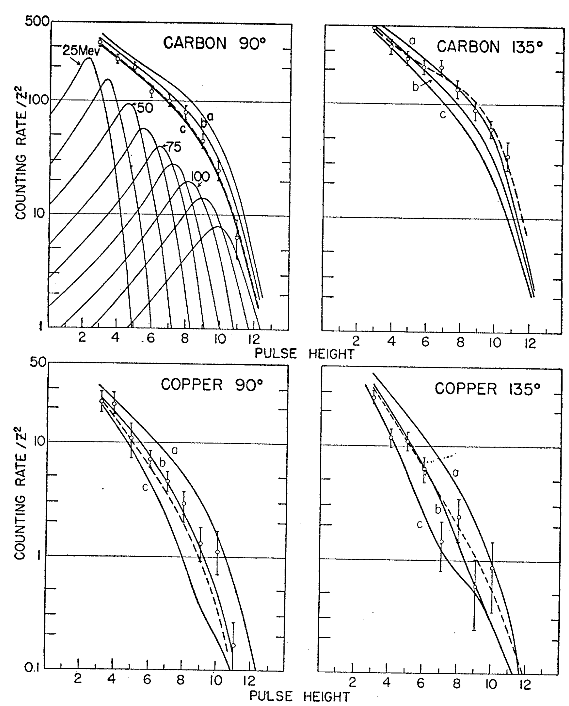

Fig. 1. Typical data for one light and one heavy element. Curves *a*, *b*, and *c* are theoretical response curves of counts *vs* pulse height computed using Thompson scattering only by a uniform distribution of free, classical protons in a nucleus of radius $R = R_0 A^{\frac{1}{3}} \times 10^{-13}$. (a) $R_0 = 0.8$; (b) $R_0 = 1.1$; and (c) $R_0 = 1.4$. The dotted curves are identical with (b) except that they use the modified Thompson cross section $\sigma_{(n+p)}{}^0$ "obs" shown in Fig. 2. The theory and experiment are on the same absolute scale; neither ordinate nor abscissa is normalized arbitrarily.

anomalous effects may be considerably quenched in heavy elements.

Classically, the large backward scattering can be explained by attributing a frequency-dependent magnetic susceptibility to the nucleons with a resonance at the meson absorption peak. The parameters of such a resonance can be determined from the total magnetic dipole absorption of a deuteron at meson resonance and from the resonant half-width. The ratio of 135° to 90° scattering predicted by this simple model is in agreement with the experiment.

The apparent reduction in scattering at 90° could be attributed to a large radius ($R_0=1.3$ for C; $R_0=1.6$

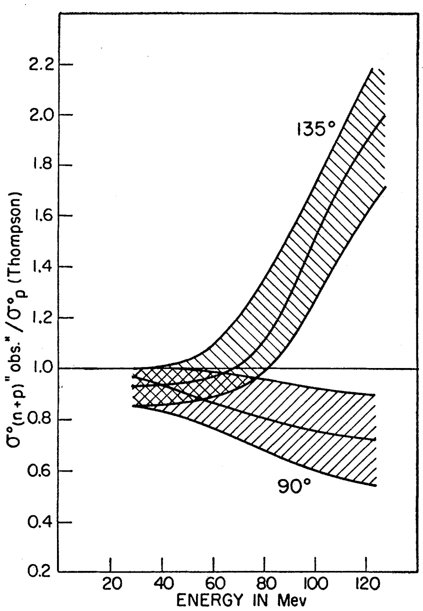

FIG. 2. Ratio of the "neutron+proton" γ-ray cross section "observed" in Be and C to the classical proton Thompson cross section.

for Be) for light elements, and/or to the electric susceptibility of the nucleons. A classical resonance calculation for electric dipole meson production predicts a reduction in the 90° cross section comparable with what is observed.

Thus far, no experiments have been done to separate neutron and proton effects on the scattering cross section. In view of the alleged charge independence of photomeson reactions, it seems reasonable that both contribute equally to the anomalous scattering. That is why a deuteron was used in the calculation of magnetic dipole oscillator strength.

A more sophisticated phenomenological calculation for protons just received from Gell-Mann, Goldberger, and Thirring is likewise in agreement with the data, provided that only protons give anomalous effects. If the neutrons contribute comparably to the anomalous scattering, then their scattering amplitudes seem to be a factor of two larger than fits the data. This disagreement may indicate some quenching of meson effects in complex nuclei. However, more accurate data, including probably a hydrogen-deuterium comparison, is necessary before such conclusions can be drawn experimentally.

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† Eastman Fellow.

Small-Angle Neutron-Proton Scattering at 400 Mev*

A. J. HARTZLER, R. T. SIEGEL, AND W. OPITZ†
Carnegie Institute of Technology, Pittsburgh, Pennsylvania

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THE previously reported[1] differential *n-p* scattering measurements at 400 Mev have now been extended to cm neutron scattering angles below 40°. In this region the energy of the recoil protons is too low for detection with a scintillation telescope, so an arrangement for observing the scattered neutrons has been used. The properties of the neutron beam, details of collimation, and the monitoring arrangement were described in reference 1. For the small-angle measurements the diameter of the beam was reduced slightly to $2\frac{1}{2}$ in. at the scatterer, which was at least 4 in.×4 in. in all cases. Extra lead shielding was also added near the scattering table to reduce neutron background.

Two types of scatterers were used, one of liquid hydrogen in a Styrofoam container and the other a pair of polythene and graphite plates which contained equal numbers of carbon atoms. The data taken with the two sets were in agreement, and both are included in the results quoted in Table I.

The apparatus is shown in Fig. 1. A thin (0.48 cm) anticoincidence counter (A), 7.6 cm wide by 10 cm high, screened out charged particles from the scatterer region. Following it were a polythene converter, 2.5 ×5.0×7.6 cm, which was centered 64.5 cm from the scatterer and determined the solid angle; a $3\times6\times\frac{1}{2}$ cm stilbene crystal (B); 5.08 cm of Cu absorber; a $4\times6\times\frac{1}{2}$

TABLE I. Relative *n-p* cross sections at small angles, normalized to $d\sigma/d\Omega=1.00$ at 40°. Column B contains results obtained with a neutron detector; column D those measured with a recoil proton telescope.

A Lab angle Θ	*B* Relative $(d\sigma/d\Omega)_{c.m.}$	*C* C.m. angle θ	*D* Relative $(d\sigma/d\Omega)_{c.m.}$
5.8	1.12±0.63	12.7	
6.8	1.33±0.14	15	
9.1	0.92±0.11	20	
13.8	0.85±0.17	30	
18.5	1.00±0.07	40	1.00±0.06
23.0	1.05±0.13	50	1.01±0.04
27.8	0.63±0.12	60	0.75±0.02