TABLE I. Level parameters for the 15.08-MeV state in ^{13}N as determined by decay and resonance methods. The total width Γ and proton elastic-scattering partial width Γ_p are given in the laboratory frame in electron volts. Uncertainties assigned in the present analysis are standard deviations among the widths determined at the four angles.

	Decay method Ref. 1	Resonance method Ref. 2	Present
Γ	930±130	1200±100	1010±30
Γ_p	220±25	230±10	285±15

eV, in strong disagreement with the value from the decay method. The comparison in Table I shows the importance of atomic-excitation effects on this resonance, and resolves the previous discrepancy between the decay and the resonance methods of determining Γ. The partial width Γ_p does not agree as well as do Refs. 1 and 2, a result for which we do not have an explanation, even though our results are based on the analysis of much more varied data than in Ref. 2.

Atomic-excitation effects similar to those investigated here are expected for other light nuclei,[8] and should be manifested by narrow resonances. Measurement of the corresponding spectrum of atomic excitation indicated in Fig. 1(b) is a challenge to atomic physicists and would provide data for further study of the interplay between atomic and nuclear physics.

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Photodisintegration of Quasifree Nucleon-Nucleon System in the Beryllium Nucleus

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Momentum spectra of protons in the reaction of γ + Be→p + anything in the incident energy range from 180 to 420 MeV were measured. The spectrum obtained shows two peaks which are interpreted to be due to the protons in reactions γ + "N" →p + π and γ + "d" →p + n, where "N" and "d" are the quasifree nucleons and neutron-proton systems, respectively, in the beryllium nucleus.

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A measurement was performed of the momentum spectrum of the photoproduced protons from the beryllium nucleus in order to investigate the nucleon-nucleon correlations or nuclear clustering effects inside the nucleus. A photon tagging system at the 1.3-GeV electron synchrotron at the Institute for Nuclear Study, University of Tokyo, was used. The incident energy range covered by this measurement was from 180 to 420 MeV with a bin width of 40 MeV. A magnetic spectrometer, which was a complex consisting of proportional wire chambers, wire spark chambers, triggering scintillation counters, and an analyzing magnet, was used to detect protons emitted from the target at laboratory angle 25° ± 5°. The spectrometer which accepted protons with momentum greater than 320 MeV/c had a momentum resolution of ± 3% at 500 MeV/c. The separation of protons from pions and deuterons was made by a measurement of the time of flight between two triggering counters in the spectrometer. In order to detect charged particles in coincidence with the protons detected by the spectrometer, scintillation counter telescopes are placed around the target opposite the spectrometer side.

The momentum spectra at various incident energies are shown in Fig. 1. At higher incident energies the momentum spectra have two broad peaks, each of which is well fitted by a Gaussian distribution. The location of these peaks varies as a function of incident energy, and at lower energies one of the peaks extends below the minimum spectrometer acceptance momentum.

Since the wavelength of incident photons is approximately equal to or even smaller than the size of a nucleon, it is expected that the target particles capable of producing protons by absorbing the incident photons are the nucleons inside the nucleus. For the peak at lower momentum, the location and its variation as a function of incident energy indicate that the protons in this peak come mainly from the recoil protons in the reactions

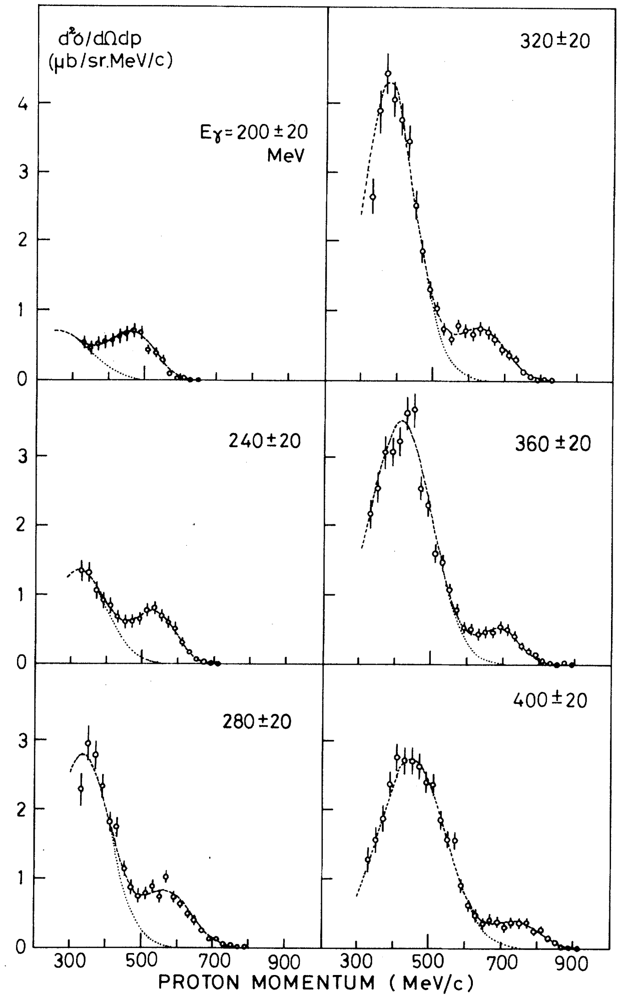

FIG. 1. Momentum spectra of the protons at the laboratory angle 25° ± 5° in the reaction $\gamma + \mathrm{Be} \rightarrow p + \text{anything}$. The dotted curves are Gaussian fits of the first peak.

$$\gamma + \text{“}p\text{”} \rightarrow p + \pi^0, \qquad (1)$$

$$\gamma + \text{“}n\text{”} \rightarrow p + \pi^-, \qquad (2)$$

where "p" and "n" denote the quasifree protons and neutrons inside the nucleus. The width of the peak is understood to be due to the difference in the binding energies of the protons and neutrons as well as due to Fermi motion of the target protons or neutrons. By integrating this peak over proton momentum, we can get $d\sigma(k)/d\Omega$. The experimental value of the cross section thus obtained is consistent with the conventional weighted sum of the cross sections of the reactions (1) and (2), $Z^{2/3}d\sigma(1)/d\Omega + N^{2/3}d\sigma(2)/d\Omega$, for π production from free protons and neutrons, respectively. Z is the number of protons and N is the number of neutrons in the beryllium nucleus. Then, what is the peak at higher momentum? It is noted as shown in Fig. 2 that this second peak almost disappears when the coincidence between the spectrometer and any one of the telescopes surrounding the target is required. This means that most of the protons in this region do not accompany any detectable charged particle. This fact, together with the location of the peak and its change as a function of the incident energy, indicates that the protons in this peak region come mainly from the reaction

$$\gamma + \text{“}d\text{”} \rightarrow p + n, \qquad (3)$$

where "d" denotes the quasifree deuterons or deuteronlike proton-neutron systems inside the nu-

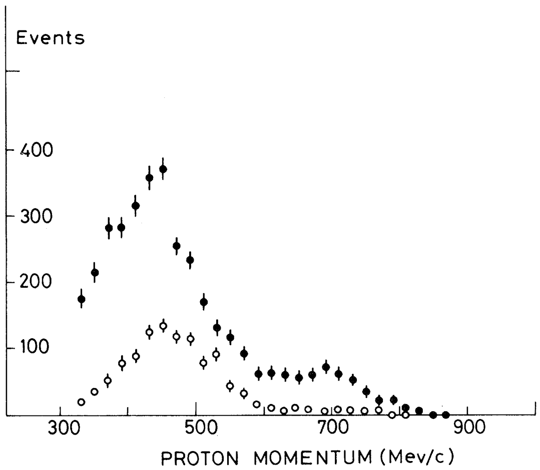

FIG. 2. Momentum spectrum of the protons at $E_\gamma = 360 \pm 20$ MeV. The solid circles represent the reaction $\gamma + \mathrm{Be} \rightarrow p$ + (charged particle) + anything.

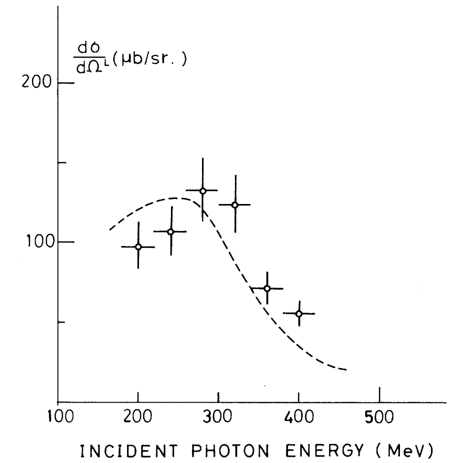

FIG. 3. The integrated cross sections $d\sigma(\gamma + \text{"}d\text{"} \rightarrow p + n)/d\Omega|_{\mathrm{Be}}$ as a function of incident energy. The dotted curve is $13 \times d\sigma(\gamma + d \rightarrow p + n)/d\Omega|_{\mathrm{free}}$ for similar kinematical conditions. The errors indicated are the quadratic sum of statistical and systematic uncertainties.

cleus. The existence of the second peak in the momentum spectrum provides, therefore, clear evidence of the presence of neutron-proton correlation in the nucleus.

The cross section for the reaction (3) is obtained by the integration of this peak over the proton momentum in this region. The cross sections thus obtained, $d\sigma(k)/d\Omega$, are shown in Fig. 3 as a function of incident photon energy. The dashed curve in Fig. 3 shows the cross sections for the photodisintegration of free deuterons given by Dougan *et al.*[1] for kinematical conditions similar to those of the present experiment. In this comparison, the corrections due to the final-state interactions of protons inside the beryllium nucleus and due to the binding effects of the proton-neutron system in the beryllium nucleus were not taken into account. The factor of 13 is very close to the predicted value (14.2 for Be) from a simple quasideuteron model given by Levinger,[2] and is consistent with the results obtained by Andersson *et al.*[3] in the analysis of their experiment on the photoproduction of protons from Be.

Although several authors[4-5] have reported the momentum spectrum of photoproduced protons from carbon for incident energies similar to those in the present experiment, their results are not conclusive as to the presence of the high-momentum peak, suggesting a neutron-proton correlation inside the nucleus. This might be mainly because they measured the proton spectrum at larger angles, where one might expect more smearing due to final-state interactions.

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