constant is long enough to allow the CaI_2(Tl) pulses to approach saturation. Under these conditions the decay constant $(1/e)$ for CaI_2(Tl) has been measured as 1.1 ± 0.1 microsecond. A small correction has been included for the superimposed decay of the load circuit.[1] Under the same conditions the pulse heights of CaI_2(Tl) and NaI(Tl) have been compared and are equal within the experimental error ($\sim$3 percent). Applying again the small corrections caused by the load circuit, the integrated light output for CaI_2(Tl) is 10 percent larger than that of NaI(Tl). [Possibly a larger result might be obtained with a single crystal of CaI_2(Tl).] This result has been obtained with both 5819 photomultiplier and with the ultraviolet sensitive (C7140) counterpart of this tube. A large fraction of the emitted light lies in the blue-green so that the output should be nearly the same in both tubes, as found. The large pulse size of CaI_2(Tl) may possibly make this crystal useful in measurements of energies of gamma-rays.

With the same apparatus, Harshaw-supplied crystals of CsI(Tl)[2] have been examined. The integrated light output for CsI(Tl) is about 0.28 ± 0.03 that of NaI(Tl) as measured with a 5819 tube and 22-microsecond load circuit. The decay constant $(1/e)$ for CsI(Tl) is also 1.1 ± 0.1 microsecond. This value agrees with an earlier determination made by one of the authors and Mr. E. C. Booth at Princeton University.

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[1] Specifically we take the voltage curve to be $V=I_0R[\tau/(\tau_0-\tau)]\times(\exp(-t/\tau_0)-\exp(-t/\tau))$, where the scintillator light output is proportional to $I=I_0\exp(-t/\tau)$ and τ_0 = time constant of load circuit $=RC$.

[2] R. Hofstadter, Research Revs. (ONR) 1, 4 (September, 1949); Nucleonics 6, 70 (1950).

The Interaction of π-Mesons with Carbon Nuclei*

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IN an earlier experiment[1] an investigation of the interaction of positive and negative π-mesons with carbon and aluminum nuclei was begun. The work with carbon has now been considerably extended. The experimental arrangement used is very similar to that of the earlier experiment (see Fig. 1 of reference 1). π-mesons, produced in targets placed in the 310-Mev bremsstrahlung beam of the synchrotron, are focused by a double magnet system into a 12-inch cloud chamber containing 9 thin carbon plates. The mesons incident on the cloud chamber have an initial energy of 65 ± 5 Mev; their energy in the chamber is primarily between 35 and 60 Mev, averaging 48 Mev.

The pictures have been analyzed stereoscopically and only events and traversals occurring within a prescribed region have been counted. Deflections in a plate with no perceptible change of ionization (<10–15-Mev energy loss) have been classified as elastic scatterings. All other events—inelastic scatterings and 0-, 1-, 2-, and 3-prong stars—have been classified as nuclear interactions. The data are presented in Table I.

The elastic scatterings with angles <20° include a large number of undetected π-μ decays occurring in or near the plates. Twelve of the 17 events in this group are expected to be π-μ decays or coulomb scatterings. The remaining five events agree well with the number of scatterings expected from the calculated diffraction pattern, assuming that all elastic scatterings are diffraction scatterings.

TABLE I. The number of nuclear interactions, scatterings, and traversals observed.

	Nuclear interactions (stars and inel. scat.)	Elastic scatterings 10°–20°	20°–75°	>75°	No. of traversals of 0.520 g/cm² C plates
π^+	33	10	11	2	6133
π^-	20	7	8	0	3310
Total	53	17	19	2	9443

TABLE II. The corrected mean-free-paths and corresponding cross sections for nuclear interactions and elastic scatterings.

	Nuclear interactions (stars and inel. scat.) λ_{ni}, g/cm²	σ_{ni}, mb	Elastic scatterings (>20°) λ_{el}, g/cm²	σ_{el}, mb	Total diffraction scat. (>0°) λ_d, g/cm²	σ_d, mb
π^+	93 ± 16	214 ± 37	255 ± 75	78 ± 23	....	....
π^-	83 ± 19	240 ± 54	210 ± 75	96 ± 34	....	....
Total	89 ± 13	223 ± 32	237 ± 55	84 ± 19	175 ± 35	115 ± 25

One of the π^+ scatterings with angle >20° can be expected to be an undetected π-μ decay. The number of traversals must also be corrected for a 3 percent contamination[1] of the beam by μ-mesons and electrons. After making these corrections, the cross sections listed in Table II have been calculated. From the diffraction angular distribution, about 75 percent of the total number of diffraction scatterings are expected to occur with angles >20° and outside of the solid angle obscured by the carbon plate containing the event. Thus, the total diffraction cross section has been calculated on the basis of (21–1)/0.75 or 27 scatterings. The errors indicated are the statistical standard deviations.

These results agree with those of the previous experiment.[1] As we observed earlier,[2] the cross sections for π^+- and π^--mesons are equal within the present statistics. Contrary to the measurement of Steinberger and collaborators[3] with 85-Mev π^--mesons, we find the carbon nucleus considerably transparent (Table III). The difference may be a result of the energy dependence of the interactions.

From the opacity ($=\sigma_{ni}/\pi R^2$) one can calculate the mean-free-path λ of π-mesons in nuclear matter and the corresponding cross section σ_i for interaction of a meson and a nucleon in the nucleus. This has been done for several values of the nuclear radius R (Table III) to indicate the variation of the various quantities with this uncertain parameter. The unusually large value of r_0 in column 4 has been included to indicate the possible effect of the meson's finite wavelength. From the transparent nucleus theory[4] as extended by Bethe and Wilson,[5] one can calculate the average potential in the nucleus V_0 and from this the total scattering cross section σ_s of a meson by a nucleon: $\sigma_s=0.735r_0^6V_0^2\mu b$, where r_0 is measured in units of 10^{-13} cm and V_0 in Mev. This calculation[5] assumes that the amplitudes for scattering a meson by a proton, a_P, and a neutron, a_N, are isotropic and equal in magnitude and sign.

For pseudoscalar mesons, the amplitudes would have the same sign for pseudoscalar coupling, and opposite signs for pseudovector coupling.[6] Anderson[7] has measured the total scattering cross section of 50-Mev mesons by protons: 11 ± 5 mb for π^- and 37 ± 8 mb for π^+-mesons. If a_P and a_N have the same sign, one would expect in carbon $\sigma_s\approx|\frac{1}{2}(37^{\frac{1}{2}}+11^{\frac{1}{2}})|^2=22\pm5$ mb, which disagrees considerably with our calculated σ_s. If they have opposite signs, $\sigma_s\approx|\frac{1}{2}(37^{\frac{1}{2}}-11^{\frac{1}{2}})|^2=1.9\pm1.4$ mb, which agrees very well. This indicates that a_P and a_N have opposite signs and that the coupling is probably pseudovector.

TABLE III. Nuclear and interaction parameters calculated from the observed σ_{ni} and σ_d.

$r_0=RA^{-\frac{1}{3}}$, $\times10^{13}$, cm	1.37	1.47	1.70
Opacity $=\sigma_{ni}/\pi R^2$	0.72 ± 0.10	0.63 ± 0.09	0.47 ± 0.07
λ, mean free path of meson in nuclear matter, $\times10^{13}$, cm	3.0 ± 1.0	4.3 ± 1.1	7.8 ± 1.6
σ_i, cross section for interaction of meson and nucleon in the nucleus, mb	36 ± 12	31 ± 8	27 ± 6
V_0, Mev	15 ± 15	15 ± 9	12 ± 5
σ_s, total scattering cross section of meson by nucleon, mb	$1.1^{+3.3}_{-1.1}$	$1.7^{+2.6}_{-1.5}$	$2.5^{+2.5}_{-1.6}$

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Photoproton and Photoneutron Relative Yields

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Marquez[1] has suggested a model for photonuclear reactions for the lighter elements in which the gamma-ray is absorbed by a single nucleon in a process similar to the photoelectric effect. There are many indications[1] that neither a statistical model in which nucleons evaporate from a compound nucleus nor a resonance model can fully explain photonuclear reactions in the light elements. If there is single particle interaction, as in the model of Marquez, one would expect the ratio $\sigma_{(\gamma,p)}/\sigma_{(\gamma,p)}$ to equal unity for different isotopes of the same light elements. This may be expected to be a more stringent test than the requirement that the ratio $\sigma_{(\gamma,p)}/\sigma_{(\gamma,n)}\cong 1$.

The betatron spectrum of 0- to 48-Mev gamma-rays were used to induce (γ,n) and (γ,p) reactions in magnesium and silicon. In order to measure (γ,p) to (γ,n) yield ratios in two different sets of magnesium isotopes a bar of spectroscopically pure magnesium metal was mounted directly in the beam and counted in place immediately after the beam was turned off. Changing the energy of the beam from 35 to 48 Mev or changing the shape and size of the sample produced no effect greater than the intrinsic errors of the experiment. This produced no effect greater than the intrinsic errors of the experiment. This was to have been expected since Perlman and Friedlander[2] have shown that relative yields are not affected by changing the beam maximum energy from 50 to 100 Mev. In all cases the relative yields reported here were determined by measuring the activity of the product nuclei. Two-particle reactions such as (γ,d), (γ,pn), and $(\gamma,2n)$ which produce the product nuclei have been neglected in computing relative yields. The results of the (γ,p) to (γ,n) yield ratios for two different sets of magnesium isotopes and the (γ,p) to (γ,p) yield ratio for a single set of magnesium isotopes are given in Table I.

In the case of elemental silicon the great difference of positron and electron energies in the (γ,n) and (γ,p) products makes an accurate yield ratio of (γ,p) to (γ,n) impossible with the set up used to determine this yield ratio in magnesium. However, it was possible using the traditional set up of bombarding and removing a thin sample to a shielded counter to obtain a yield ratio of (γ,p) to (γ,p) for silicon. The silicon used had no spectroscopic observable impurities greater than 0.003 of a percent and was bombarded in the form of a fine powder. Mountings were such as to reduce backscattering and absorption to a minimum. Except for the (γ,n) yield on magnesium in which the size of the sample was specifically studied, all yields were corrected for absorption using the curves of Perlman and Friedlander.[2]

The (γ,p) irradiations on silicon were monitored by measuring the C^{11} activity induced in a weighed amount of spectrographically pure powered graphite. The monitors presented to the beam the same area cross section as did the targets and were always mounted in tandem. Only a single radioactive species was observed in the monitor over a period of six half-lives.

The relative yields of (γ,p) to (γ,p) for two silicon isotopes are shown in Table I. With the use of the monitor it is possible to compare the (γ,p) on Si^{30} to that obtained by Perlman and Friedlander.[2] The agreement is shown in Table I and is within experimental error.

Although it is not easily possible to make quantitative calculations because of the complexity of the betatron gamma-ray spectrum, it is immediately apparent that these are further data not easy to reconcile with the idea of evaporation from a compound nucleus. The energetics of proton or neutron emission in a compound nucleus determine the competition between the (γ,n) and the (γ,p) cross section. If the probability of creating the compound nucleus is assumed to be approximately the same for different isotopes of the same element, then from the energetics one would expect in general the Γ_p/Γ_n to be very different for different isotopes of the same element. Specifically, one expects for any model involving a compound nucleus the (γ,p) to (γ,p) yield ratios to be very different from one for the different isotopes of both Mg and Si. In the case of silicon the ratio $\sigma_{(\gamma,p)}/\sigma_{(\gamma,p)}$ equals unity within the experimental error for the isotopes Si^{29} and Si^{30}. In the case of magnesium the ratio is 1.82 ± 0.25 for the isotope ratio Mg^{25}/Mg^{26}. This relatively high yield of Na^{24} may have arisen from its production by the process $Mg^{26}(\gamma,pn)Na^{24}$. It would appear from these limited data that there is a considerable contribution to photonuclear reactions for light elements of the type proposed by Marquez.[1]

TABLE I. Ratios of yields of (γ,n) and (γ,p) reactions.[a]

Parent isotope	Reaction	Product half-life	Product betas and energy (Mev)	Ratio of yields (this research)	Ratio of yields (Perlman and Friedlander)[b]
Si^{29}	(γ,p)	2.30 min	3.01		
				1.12 ± 0.16	...
Si^{30}	(γ,p)	6.56 min	2.5 (70 percent) 1.4 (30 percent)		
				2.67 ± 0.31	2.87
C^{12}	(γ,n)	20.35 min	0.970		
Mg^{25}	(γ,p)	14.9 hr	1.390		
				1.82 ± 0.25	...
Mg^{26}	(γ,p)	62.5 sec	3.7 (55 percent) 2.7 (45 percent)		
				$3.6\ \pm0.5$	...
Mg^{24}	(γ,n)	11.9 sec	2.82		

[a] Note that the yield is given in between the columns of the parent isotopes and reactions which determine the yields. Thus the value 1.12, in between the Si^{29} and Si^{30} columns refers to the (γ,p) yield on $Si^{29}/(\gamma,p)$ yield on Si^{30}.
[b] See reference 2.

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[2] M. L. Perlman and G. Friedlander, Phys. Rev. **74**, 442 (1948).

An Asymmetric Nuclear Model

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We want to discuss here some features of an asymmetric nuclear shell model proposed by Rainwater.[1] This model may be fitted to predict nuclear quadrupole moments of the right order of magnitude.

We consider a core formed by the nucleons grouped in saturated orbits; this core is treated as a liquid drop whose surface acts on the remaining nucleons (which we shall call extranucleons) as an impenetrable barrier. It is also assumed that there is a strong spin-orbit coupling of the type:

$$\text{const. } \mathbf{l}\cdot\mathbf{s}. \tag{1}$$

The shape of the core may be described by:

$$R(\mu)=R_0[1+\Sigma_n\,\alpha_n P_n(\mu)], \tag{2}$$

R_0 being the radius of the undistorted core.

If deviations from the spherical shape are small, a perturbation method already described[2] may be applied to the calculation of