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C and Al Photoproton Angular and Energy Distribution.

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1. – Introduction.

The abnormally high photoproton yields observed for elements of high atomic number (Weinstock and Halpern (¹), Toms and Stephens (²,³)) indicate that the simple evaporation model is inadequate. A better fit with experimental results is given by the direct interaction model (Courant (⁴)). However the compound nucleus theory can in some cases account for the experimental (γ, p) cross-sections if a lower proton barrier is assumed (Spicer (⁵)) or some « ad hoc » assumptions are made on the level density of the residual nucleus (Spicer (⁵), Butler and Almy (⁶)).

No consistent and unique theory of the nuclear photoeffect seems at present to be generally satisfactory (for instance photoprotons are emitted according to the statistical theory from ^{92}Mo and according to the direct process for ^{100}Mo) (Butler and Almy (⁶)) and more detailed informations are then necessary about the photoeffect in a single nucleus.

We decided therefore to measure energy spectra and angular distributions of photoprotons in ^{12}C and ^{27}Al, firstly because these natural elements are practically pure isotopes and secondly because their (γ, p) cross-sections are well known (Halpern and Mann (⁷)). Also the (γ, n) cross-sections for carbon (Montalbetti *et al.* (⁸)) have been measured.

Comparison between (γ, p) and (γ, n) cross-sections for these nuclei shows that they are very similar in the region around the giant resonance. This behaviour which might be due mainly to a resonance in the absorption cross-section for photons, justifies further investigation of the photoeffect in these nuclei.

(¹) E. V. Weinstock and J. Halpern: *Phys. Rev.*, **94**, 1651 (1954).

(²) M. E. Toms and W. E. Stephens: *Phys. Rev.*, **92** 362 (1953).

(³) M. E. Toms and W. E. Stephens: *Phys. Rev.*, **98**, 626 (1955).

(⁴) E. D. Courant: *Phys. Rev.*, **82**, 703 (1591).

(⁵) B. M. Spicer: *Phys. Rev.*, **100**, 791 (1955).

(⁶) W. A. Butler and G. M. Almy: *Phys. Rev.*, **91**, 58 (1953).

(⁷) J. Halpern and A. K. Mann: *Phys. Rev.*, **83**, 370 (1951).

(⁸) R. Montalbetti, L. Katz and J. Goldemberg: *Phys. Rev.*, **91**, 659 (1953).

2. – Experimental Procedure.

Aluminium and carbon targets in form of 4 mm diameter disks were exposed to the collimated 31 MeV bremsstrahlung beam from the Brown-Boveri betatron of the University of Turin (Fig. 1). The aluminium disk was 66 μm thick and the carbon disk 200 μm. Photoprotons were detected in 200 μm C_2 Ilford 3″ × 3″ plates, placed together with the target T in an evacuated camera.

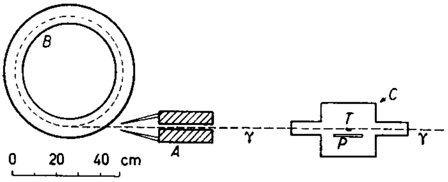

Fig. 1. – Experimental arrangement for photoprotons angular distribution measurements. A = lead collimator; C = exposure chamber; T = target; P = photoplate; B = betatron doughnut.

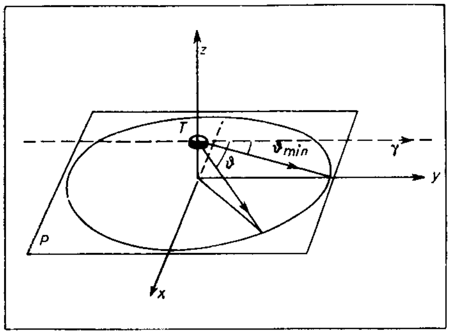

Fig. 2. – Geometry of the experimental arrangement for photoprotons angular distribution measurements. P = photoplate; T = target.

To measure the angular distribution of the photoprotons, photoplates were exposed parallel to the beam and 1 cm apart (Fig. 2). Targets were fixed in the center of the beam and parallel to it. Only photoprotons ejected from the target with an angle $16° < \vartheta < 164°$ from the beam axis entered the scanned area of the emulsion and from the geometry of the experiment it was easy to control if the protons were originated in the target. Very few protons were observed when the target was removed from the chamber.

In order to measure the energy distributions, targets and photoplates were exposed normally to the beam: targets, 0.5 mm thick, were placed 6 mm apart from the plates.

Angular distributions were obtained by grouping protons into angular intervals on the plates corresponding to equal solid angles seen from the target.

Energy distributions of photoprotons emitted from thick targets were obtained by deriving with respect to the range the observed proton spectra and converting them afterwards in energy spectra.

3. – Results and Discussion.

3·1. *Carbon*. – Photoprotons ejected from carbon with energy greater than 5.5 MeV show a pronounced forward asymmetry peaked at 60° (Fig. 3). The

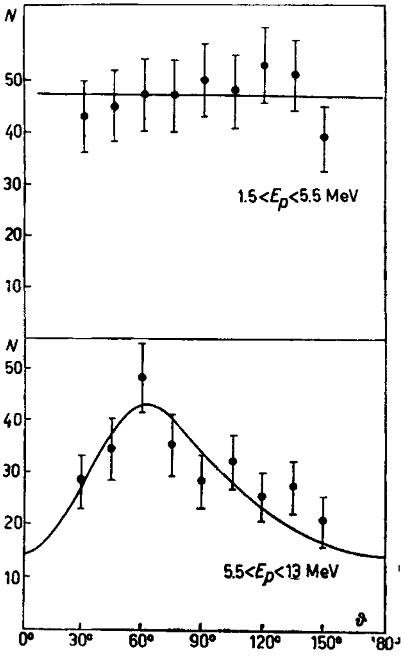

Fig. 3. – Angular distribution of photoprotons from Carbon. N = number of photoprotons observed with energy E_p for unit solid angle in arbitrary scale.

lower energy proton component has a practically isotropic distribution.

The differential cross-section for the former group of protons can be fitted by a function $0.6+(\sin\vartheta+0.6\sin\vartheta\cos\vartheta)^2$. This is to be compared with the distribution given by HALPERN, MANN and ROTHMAN (9) who found a less pronounced forward asymmetry using a bremsstrahlung beam with maximum energy 23 MeV.

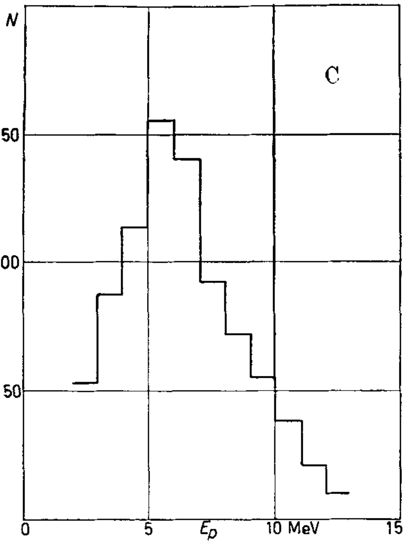

Fig. 4. – Photoproton energy distribution from Carbon irradiated at 31 MeV photon max energy. N = number of protons observed into 1 MeV interval.

JOHANSSON (10) using a 65 MeV bremsstrahlung beam observed a strong maximum at 60° for proton energy greater then 14 MeV. HENDEL (11) found a maximum at $\vartheta = 45°$ with a 150 MeV bremsstrahlung beam.

It is evident that the high energy protons are emitted with high orbital momentum, presumably corresponding to high multipole orders of photon interaction.

The proton energy spectrum shows a maximum between 5 and 6 MeV. This proton energy, taking into account the threshold value of 15.9 MeV, corresponds to the maximum of the (γ, p) cross-section as given by HALPERN and MANN (7) at 21.5 MeV photon energy. This fact strongly suggests that direct photoeffect takes place; such interpretation is supported also by the observation of the pronounced anisotropy in the angular distribution.

3·2. *Aluminium.* – The anisotropy of the angular distribution of photoprotons emitted from aluminium depends on the proton energy as shown in Fig. 5. Experimental points can be fitted by a curve $N=a+b\sin^2\vartheta$, the ratio b/a increasing with the energy of photoprotons.

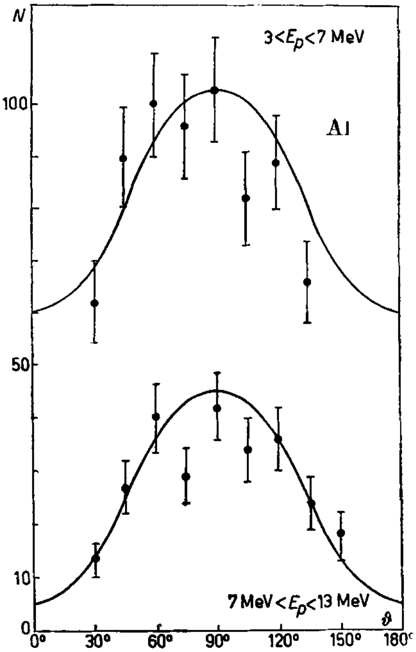

Fig. 5. – Angular distribution of photoprotons from Aluminium. N = number of photoprotons observed with energy E_p for unit solid angle in arbitrary scale.

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(9) J. HALPERN, A. K. MANN and M. ROTHMAN: *Phys. Rev.*, **87**, 164 (1952).

(10) S. A. E. JOHANSSON: *Phys. Rev.*, **97**, 434 (1955).

(11) H. HENDEL: *Zeitsch. f. Phys.*, **135**, 168 (1953).

DIVEN and ALMY (12), HOFFMANN and CAMERON (13), with respectively 22 and 25 MeV bremsstrahlung beams found almost isotropic distributions. This probability is due to the lower photon energy used and to the absence of proton energy selection.

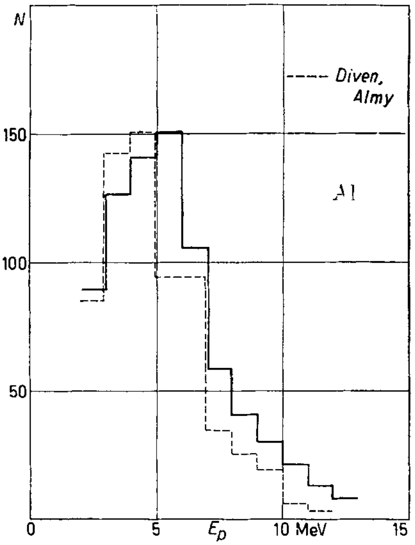

Fig. 6. – Photoproton energy distribution from Aluminium irradiated at 31 MeV photon max energy. N = number of protons observed into 1 MeV interval.

At higher $F_{\gamma\,\max}$ energies, 40 and 65 MeV, HOFFMANN and CAMERON (13) observed a pronounced maximum at 60° for proton energy between 16 and 28 MeV and between 27 and 43 MeV respectively. Also JOHANSSON with $E_{\gamma\,\max} = 65$ MeV and selecting protons with energy greater than 14 MeV found a maximum at 60°.

The proton energy spectrum from Al was measured by DIVEN and ALMY (12) with $E_{\gamma\,\max} = 20.8$ MeV and found to be peaked at 4 MeV. HOFFMANN and CAMERON (14) with an $F_{\gamma\,\max} = 25$ MeV found a maximum at 5 MeV.

Our results give a maximum at 5 MeV with a distribution similar to that measured by other authors. The (γ, pn) threshold from mass differences (MATTAUCH, FLAMMERSFELD (15)) is 19.5 MeV and therefore in present experiments the (γ, pn) reaction could have contributed to shift the maximum to lower proton energies.

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(12) B. C. DIVEN and A. K. ALMY: *Phys. Rev.*, **80**, 407 (1950).

(13) M. M. HOFFMANN and A. G. W. CAMERON: *Phys. Rev.*, **92**, 1184 (1953).

(14) L. KATZ and A. G. W. CAMERON: *Phys. Rev.*, **84**, 1115 (1951).

(15) J. MATTAUCH and A. FLAMMERSFELD: *Isotopic Report* 1949.