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A. Malecki and P. Picchi :

THE ROLE OF SHORT-RANGE CORRELATIONS IN THE NUCLEAR PHOTOEFFECT

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The Role of Short-Range Correlations in the Nuclear Photoeffect.

A. Małecki
Instytut Fizyki Jądrowej - Krakow

P. Picchi
Laboratori Nazionali del CNEN - Frascati
Laboratorio di Cosmo-Geofisica del C.N.R. - Torino

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If the nucleons strongly repelled each other at short separations this would be reflected in their momentum distribution in the nucleus, high-momentum components being considerably enriched. The characteristic momentum from which the effect of short-range correlations becomes important may be simply estimated as $p_{\text{corr}} = p_F + 1/R$, p_F being the Fermi momentum and R the nuclear radius. For small nuclei one has $p_{\text{corr}} \approx 2\ \text{fm}^{-1}$, which corresponds to a repulsive core of radius 0.5 fm.

The correlation tail in the momentum distribution might be revealed in the process where one observes the nucleons ejected from the nucleus by an energetic particle. For a large value of momentum of the outgoing nucleon either the scattered beam particle (transferring enough momentum to the nucleus), or the nuclear correlations (yielding fast nucleons inside the target) may be responsible. The first process is effective only for the nucleons ejected in the front hemisphere with respect to the beam. The energetic nucleons emitted from the target at backward angles will thus provide evidence of the correlations.

It is important to realize that, due to its large mass, the nucleon kinetic energy is much smaller than the momentum. Therefore the effect of the correlations may be observed in the purely nuclear region of excitations, *i.e.* below the threshold for meson production. A rough estimate, based on the impulse approximation, shows that $T = 80$ MeV should be enough to feel the correlations. The corresponding energy loss of the projectile is somewhat larger, $\omega > 100$ MeV, being increased by the binding and recoil of the residual nucleus.

The effects of short-range correlations on nucleon emission induced by fast electrons (¹) and high-energy hadrons (²) were discussed in previous works. Here we consider this

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(¹) A. Małecki and P. Picchi: *Phys. Lett.*, **36** B, 61 (1971).

(²) M. Błeszyński and A. Małecki: in *Proceedings of the European Conference on Nuclear Physics*, Vol. **2** (Aix-en-Provence, 1972), p. 120.

problem for a beam of energetic photons. Although the photons are mainly absorbed by nucleon pairs, there is also evidence of single-particle emission, *i.e.* the (γ, p) and (γ, n) processes. This nuclear photoeffect has already been studied in some detail (³,⁴). We share the opinion of ref. (⁴) that the *precise* description of photoemission needs, perhaps, a rather sophisticated approach. We try, however, to be slightly optimistic by pushing further the *qualitative* discussion of the correlation effects in the process.

To this end we use a very simple model in which the photon interacts with individual nucleons with a given momentum distribution $W(p)$. During the process the nucleon scatters elastically and comes out of the target, the residual nucleus being recoiled to satisfy the energy-momentum conservation. Although a photon is principally coupled to the protons, a possibility of neutron emission also exists as a result of recoil. This may be easily expressed by introducing the concept of effective charges for protons and neutrons. They should be comparable in magnitude, otherwise the cross-sections for the (γ, p) and (γ, n) reactions would differ appreciably, contrary to observed yields. With regard to the final-state interaction, one can expect that energetic photonucleons will be mostly absorbed and their elastic scattering should be concentrated at forward angles. This results in a considerable reduction of intensity, but the angular distribution of the emitted nucleons will not be greatly distorted.

Our impulse approximation model gives the following formula for the angular distribution:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\theta, E_\gamma) \sim \frac{\sin^2\theta}{E_\gamma}\int \mathrm{d}S\,\varphi(S)\,\frac{p'^3}{V_{\mathrm{rel}}ER}\,W(p)\,, \tag{1}$$

where $(E, \boldsymbol{p})$, $(E', \boldsymbol{p}')$ denote the energy and momentum of the initial and final nucleon, respectively, $\varphi(S)$ is a spectrum of the separation energy, and V_{rel} gives the photon velocity relative to the bound nucleon. The angle of emission θ is measured with respect to the beam.

The recoil factor in (1) is given by

$$R = 1 + \left(1 - \frac{E_\gamma \cos\theta}{p'}\right)\frac{E'}{E_{A-1}}, \tag{2}$$

$E_{A-1} = (A^2M^2 + p_{A-1}^2)^{\frac{1}{2}}$ being the total energy of the residual nucleus.

Energies and momenta in eqs. (1) and (2) satisfy the relations

$$\boldsymbol{p}' = \boldsymbol{p} + \boldsymbol{p}_\gamma\,, \qquad \boldsymbol{p}_{A-1} = -\boldsymbol{p}\,, \qquad E' = E_\gamma + AM - S - E_{A-1}\,. \tag{3}$$

In this model the nuclear structure is almost exclusively represented by the momentum distribution $W(p)$ of nucleons in the ground state. This $W(p)$ reflects the features of the average nuclear potential and of the nucleon-nucleon correlations. In order to calculate $W(p)$ we worked in the p-representation expressing the momentum distribution as the Fourier transform of the elastic form factor in momentum space (¹). As single-particle potential the harmonic oscillator model was used. The short-range repulsive interaction was introduced by means of unitarity operators $u(r_{jk})$ and treated in the two-particle correlation approximation (⁵). We then proceeded according

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(³) W. Weise and M. G. Huber: *Nucl. Phys.*, **162** A, 330 (1971).

(⁴) M. Fink, H. Hebach and H. Kümmel: Ruhr-Universität Bochum report (1972).

(⁵) A. Malecki and P. Picchi: *Riv. Nuovo Cimento*, **2**, 119 (1970).

to the well-known algorithm (6) for separation of the relative and c.m. motions of two particles in the oscillator field.

The correlation operators applied by us act on the radial wave function of the relative motion in the following way:

$$u(1,\,2)R_{nl}(p)=\sqrt{\frac{2}{\pi}}\,(-i)^l\int\limits_0^\infty \mathrm{d}r\,r^2 j_l(pr)R_{nl}(r)\left[\frac{g^2+(M_{nl}-1)g}{M_{nl}}\right]^{\frac{1}{2}} \tag{4}$$

with coefficients M_{nl} determined by the normalization (5); $g(r)$, being a function of the mutual distance $s=\sqrt{2}\,r$ of a nucleon pair, is supposed to vanish within a repulsive core of radius c whereafter it rapidly rises up to unity. The correlations (4) are then healed at larger separations.

In Fig. 1 *a*-*c*) we present the momentum distributions for the ^{16}O nucleus. We would like to stress that the nuclear parameters used in our calculations were checked in the earlier work (5); they fitted the data for elastic electron scattering excellently. The short-range correlations introduced in the shell model I) do not change $W(p)$ for $p<1\ \text{fm}^{-1}$, II) *reduce* $W(p)$ by $(20\div30)\%$ for $1\ \text{fm}^{-1}<p<1.8\ \text{fm}^{-1}$, III) *strongly increase* $W(p)$ for $p>1.8\ \text{fm}^{-1}$, *e.g.* at $p=2\ \text{fm}^{-1}$ we have a difference of one and at $p=2.5\ \text{fm}^{-1}$ of three orders of magnitude.

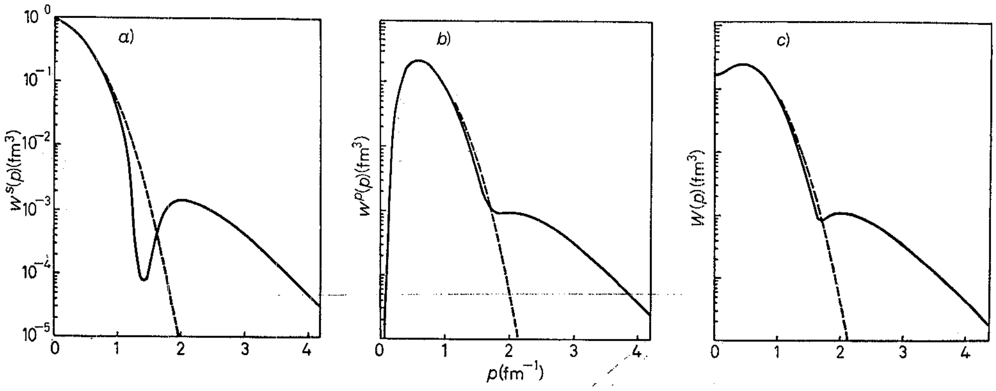

Fig. 1. – The momentum distribution (for *s*- and *p*-shell and average) in the ^{16}O nucleus. The oscillator parameter is $\alpha=119$ MeV and the correlation factor is assumed in the form $g(s)=1-\exp[-\beta^2(s^2-c^2)]$ with $c=0.54$ fm, $\beta=0.64\ \text{fm}^{-1}$ (5). *a*) *s*-shell momentum distribution, *b*) *p*-shell momentum distribution, *c*) momentum distribution. ——— Correlation, – – – shell model.

In Fig. 2 *a*), *b*) we present the angular distributions of emitted protons, obtained with the aid of eq. (1), at two photon energies. The difference of the correlation effects in the two cases is evident. At large E_γ the emitted nucleons originate from region III) of nuclear momenta. These energetic photonucleons strongly exhibit the presence of the repulsive interaction. On the other hand, at lower energies the ejected nucleons come mainly from region II), where the correlations play a minor pole.

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(6) M. Moshinsky: *Nucl. Phys.*, **13**, 104 (1959).

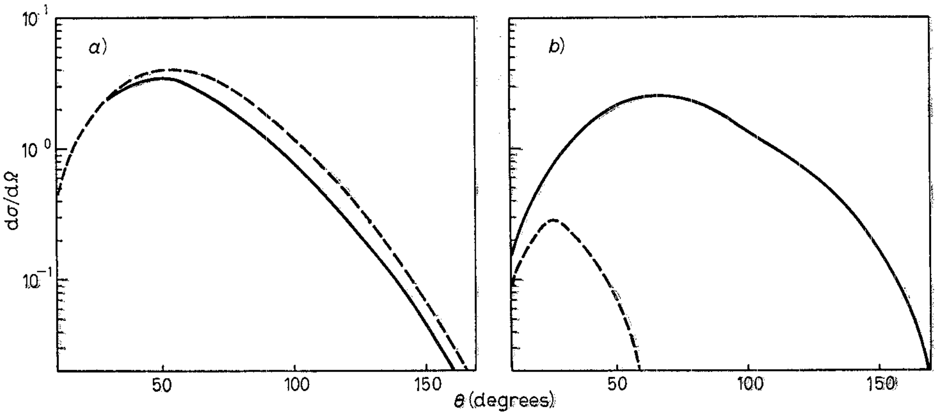

Fig. 2. – Angular distributions of photoprotons (in arbitrary units) ejected from the ^{16}O nucleus for two photon energies. The spectra of the separation energy are taken from ref. (⁷). $^{16}O(\gamma, p)$, *a*) $E_\gamma = 60$ MeV, *b*) $E_\gamma = 140$ MeV. —— Correlations, – – – shell model.

The integrated cross-section, presented in Fig. 3 as a function of photon energy, gives $E_\gamma \approx 100$ MeV as a minimum value for which the emitted photonucleons are sensitive to the nucleon-nucleon correlations. This is in agreement with the estimates made at the beginning of this note. Our results, however, disagree with ref. (³), where a large correlation effect was found for all $E_\gamma > 40$ MeV. We think that this is due to unrealistically strong repulsive correlations applied in (³). The results of ref. (⁴) confirm our conclusion.

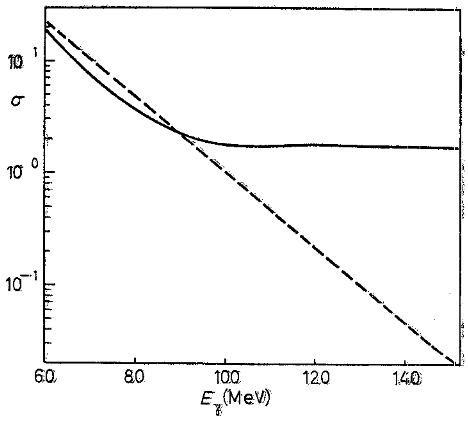

Fig. 3. – Integrated cross-section for photoemission of protons from ^{16}O (arbitrary units). $^{16}O(\gamma, p)$, —— correlations, – – – shell model.

Let us note that the total cross-section changes very little with photon energy, in a wide region of E_γ. The plateau of the cross-section, similar to that found in ref. (¹), is characteristic for the presence of short-range correlations. In the angular distribu-

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(⁷) G. Jacob and Th. A. J. Maris: *Rev. Mod. Phys.*, **38**, 121 (1966).

tion we observe that the correlations may be important even in the front hemisphere of emission angles (see Fig. 2 *b*)). This is connected with the zero mass of the photon; its momentum, being relatively small, cannot contribute much to the momentum of the ejected nucleon.

We would like to stress again that our analysis is principally qualitative. The precise description of the process would require a careful study of the transition operator as well as of the nuclear wave functions. Thus the absolute magnitude of the emission yields, the difference between the (γ, p) and (γ, n) reactions, etc. could be found. This may be a rather complicated task (4), *e.g.* in the region of large nucleon momenta a nonrelativistic reduction of the electromagnetic current could be questioned. Despite these objections, we hope that the principal features of the short-range correlations discussed in this note remain unchanged in a sophisticated analysis.