On High Energy Photoneutrons.

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Recent experimental investigations on the nuclear photoeffect have shown the existence, at least for some nuclei, of a secondary maximum in the \((\gamma, n)\) cross section at a photon energy greater than the giant resonance one \(^{(1)}\), and of a peak in the energy spectra of the photoneutrons, between 4 and 6 MeV, contributing about 10% to the total yield \(^{(2)}\).

Wilkinson's theory \(^{(3)}\) does not predict such peaks; in particular the energy spectra of directly photoejected neutrons are expected, according to that theory, to be similar in form to those of the \(\langle\text{evaporated}\rangle\) neutrons, with a somewhat longer high energy tail. On the other hand Wilkinson's theory correctly predicts the amount of directly photoejected nucleons \(^{(4)}\) but such nucleons may also contribute to the high energy part only of the total yield \(^{(5)}\), in disagreement with Wilkinson's prediction on the energy spectra of those particles.

In what follows we will attempt to understand the quoted new features of the nuclear photoeffect in the frame of Wilkinson's theory with the additional hypothesis that directly photoemitted nucleons have to be observed, on the average, with the energy of the virtual Shell Model state whose properties their motion shares just before they leave the nucleus. We will take into account, of course, single particle dipole transitions also when they give a minor contribution to the giant resonance in the photon absorption cross section, but we will choose a somewhat qualitative definition of the relevant single particle level spectrum.

To be more precise about this spectrum, we point out that the basic Wilkinson's assumption, namely that the giant resonance is an effect of the grouping in energy of the \(11\) to \(11\frac{1}{2}\) dipole transitions from saturated to unoccupied Shell Model levels, implies that \(E_{\gamma}\), the giant resonance energy, gives the average energy difference bet-


\(^{(2)}\) G. CORTINI, C. MILONE et al.: Experimental results on Ta and Cr photoneutron spectra (to be published): private communication.


\(^{(4)}\) This is implied from the agreement of calculated and experimental ratio of proton emission to total absorption in the heavy elements, as shown in \(^{(5)}\) p. 1067.

ween the relevant levels, the lower one, in each pair, being known for a given nucleus from Shell Model considerations. The energy of the last filled level is roughly \(-E_t\), being \(E_t\) the threshold energy either of the \((\gamma, n)\) reaction, for a neutron transition, or of the \((\gamma, p)\) reaction for a proton transition.

Furthermore, it is well known that in the Nuclear Shell Model the spin-orbit splitting of \(l\)-levels must be taken into account, but this splitting is unessential in Wilkinson's theory: this amounts to say that one can safely assume the unoccupied levels to be splitted in the same way (and with the same strength parameter) as the occupied ones.

The previous remarks strongly suggest to introduce the further assumption that the relevant virtual level spectrum has the same features of the shell model one. This spectrum somehow intermediate between that of the Isotropic Harmonic Oscillator Well and that of the Square Well with infinitely high walls, and with \(l\)-levels splitted by spin-orbit coupling, may be assumed as a phenomenological one, in the sense that it gives the ordering and grouping of the stationary single particle levels in terms of which the shell theory explains so many regularities in nuclear phenomena.

With the above outlined scheme, and by considering nuclei with no neutrons outside saturated shells, definite predictions can be given about photoneutrons yields and spectra. Nuclei with \(A\) less than 20 will not be considered, being well known that in processes involving such nuclei \(\alpha\)-particle effects may be important; nuclei with \(A\) around 150 also will not be considered, owing to their usually strong deviation from spherical shape, and to possible effectiveness of collective motions in the dynamics of their structure. In the range of \(A\) values between 20 and, say, 110 (\(^{115}\)In has a great electric quadrupole moment) some preliminary calculations have been carried out by the present author and it seems that the existence of the peak around 5 MeV in the neutron energy spectra can be reasonably well explained. Such a peak is predicted in fact for \(^{40}\)Ca, \(^{51}\)V, \(^{52}\)Cr, \(^{89}\)Y, usually contributing about 12\% to the total yield, and it is expected that nuclei with few protons less or with few neutrons more than those quoted above will not give significantly different results.

Now, in order to test definitely the consistency of such an explanation it is worthwhile to investigate wether departures from the general trend (with the peak around 5 MeV in the energy spectra) outlined just above, are expected on the basis of the present scheme.

This happens to be the case for \(^{103}\)Rh: in fact it may be expected that, working with a bremsstrahlung spectrum with about 30 MeV maximum energy, the neutrons from the \(^{103}\)Rh \((\gamma, n)\) process have a peculiar \(\#\)\# peak, in their energy spectrum, at 8.4 MeV contributing something as 6 or 8\% to the total yield. The Rh photoneutron spectrum seems to be particularly interesting since the main contribution (84\%) to its peculiar \(\#\#\#\#\#\) peak comes from the \(1h_{11/2}\) direct photoejected neutrons.

The average energy of such neutrons is fixed, according to the present scheme, as follows: the most important contribution to the photon absorption comes from the \(1g_{9/2} \rightarrow 1h_{11/2}\) transition, and the energy difference between these levels is \(E_m = 16.5\) MeV. The spin-orbit splitting of the \(l\)-levels is expected to be \(\sim (2l+1)\beta\) being \((\beta)\) \(\beta \sim 1\) MeV for nuclei around \(^{40}\)O and \(\beta \sim \frac{1}{2}\) MeV for nuclei around \(^{208}\)Pb; so we calculate that the energy difference between the \(1g_{9/2}\) and \(1g_{7/2}\) levels will be \(\sim 6\) MeV and that between the \(1h_{11/2}\) and \(1h_{9/2}\) levels \(\sim 7.25\) MeV. The threshold energy