Nucleon Momentum Distribution in ^{16}O Using the (γ,p) Reaction

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The momentum distribution of $p_{1/2}$ shell nucleons in ^{16}O is deduced from measurements of the angular distribution of the $^{16}O(\gamma,p_0)$ reaction cross section between $E_\gamma = 40$ and 105 MeV. The results are found to deviate from the Elton-Swift distribution.

The measurement of a nucleon bound state wave function, or its Fourier transform, the momentum wave function, provides a most valuable test of any nuclear model. Hitherto momentum distributions have been investigated almost exclusively by the $(p, 2p)$ and $(e, e'p)$ quasifree scattering reactions.[1] This Letter presents new results obtained from the (γ, p) reaction, the use of which circumvents the difficulties of a coincidence measurement and has permitted the extension of the measured momentum distribution to momenta considerably higher than those previously investigated.

The analysis is based on measurements of the $^{16}O(\gamma, p_0)$ reaction cross section for photon energies above the giant resonance but below the π-meson production threshold. Angular distributions at $E_\gamma = 60$, 80, and 100 MeV comprise the bulk of the data. The experimental details of these measurements have already been described[2]; the modifications in technique employed to investigate the $^{16}O(\gamma, p)$ reaction will be given elsewhere.[3]

A momentum distribution has been extracted from the data using an extension of the plane-wave model, whereby the most important effect of distortion in the final state is approximately included in terms of a real energy-dependent optical potential V. The main effect of this potential is to reduce the energy of the photoproton by $(1 - 1/A)|V|$ as it leaves the nucleus, without much affecting its direction. The observed outgoing proton momentum $\hbar\vec{k}$ is thus related to the internal momentum $\hbar\vec{k}'$ just after the photon is absorbed by $(\hbar k')^2/2m = (\hbar k)^2/2m - (1 - 1/A)V$, $\vec{k}/k = \vec{k}'/k'$, where m is the proton mass and all quantities are defined in the center-of-mass system. The effect of the imaginary component of the optical potential is crudely approximated as an energy-independent absorption factor η, whose value was estimated[4,5] as $\eta = 0.4$. In this "extended" plane-wave approximation the (γ, p) cross section per proton in the center-of-mass system is[5,6]

$$\frac{d\sigma}{d\Omega} = 2\pi^2 \frac{A-1}{A} \frac{e^2}{mc^2} \frac{kk'^2}{k_\gamma}\left(1 - \frac{\partial V}{\partial E}\right)\eta \times \sin^2\theta \frac{1}{2l+1}\sum_m |\varphi_{lm}(\vec{q})|^2,$$

where θ is the angle of emission of the photoproton, $\hbar\vec{k}_\gamma$ is the incoming photon momentum, the momentum wave function $\varphi_{lm}(\vec{q}) = (2\pi)^{-3/2}\int \exp(-i \times \vec{q}\cdot\vec{r})\psi_{lm}(\vec{r})d^3r$, with $\psi_{lm}(\vec{r})$ the proton bound state wave function and $\hbar\vec{q} = \hbar(\vec{k}' - \{1 - 1/A\}\vec{k}_\gamma)$ the initial momentum of the bound proton, $\hbar k = [(1 - 1/A) \times (2m\{\hbar c k_\gamma - S\} + \hbar^2 k_\gamma^2/A)]^{1/2}$ with S the proton separation energy, and $1 - \partial V/\partial E$ is the Perey factor.[7] The final-state potential V is approximated by $V(E) = -V_0(1 - E/E_0)$. The energy dependence is fixed by choosing $E_0 = 200$ MeV.[8] An appropriate value for the average potential has been obtained using a procedure suggested by de Forest[9]: In the limit of zero photon energy the kinetic energy in the final state, $-V(-S) - S$, is equated to the average kinetic energy, T_b, of the bound state, i.e., $T_b = V_0(1 + S/E_0) - S$. A value of $T_b = 17$ MeV has been obtained from the Elton-Swift[10] $1p_{1/2}$ bound state wave function for ^{16}O; this gives $V_0 = 27$ MeV. Using the relations above, a value for $(2l+1)^{-1}\sum_m |\varphi_{lm}(\vec{q})|^2$ was obtained from each measured cross-section datum point $d\sigma(k_\gamma, \theta)/d\Omega$. The resultant momentum distribution points are shown in Fig. 1(a), which also illustrates the sensitivity of the distribution to somewhat extreme changes in V_0. The distribution is quite insensitive to changes in E_0 (not illustrated).

It will be noted from Fig. 1(a) that the experimental data taken over a wide range of photon energies and proton angles can be parametrized consistently in terms of a single momentum distribution. [The consistency of the data is better for this plausible choice of $V(E)$ than for the extreme values shown in Fig. 1(a)]. The cross section for the (γ, p) process depends predominantly on the probability that the nucleus can

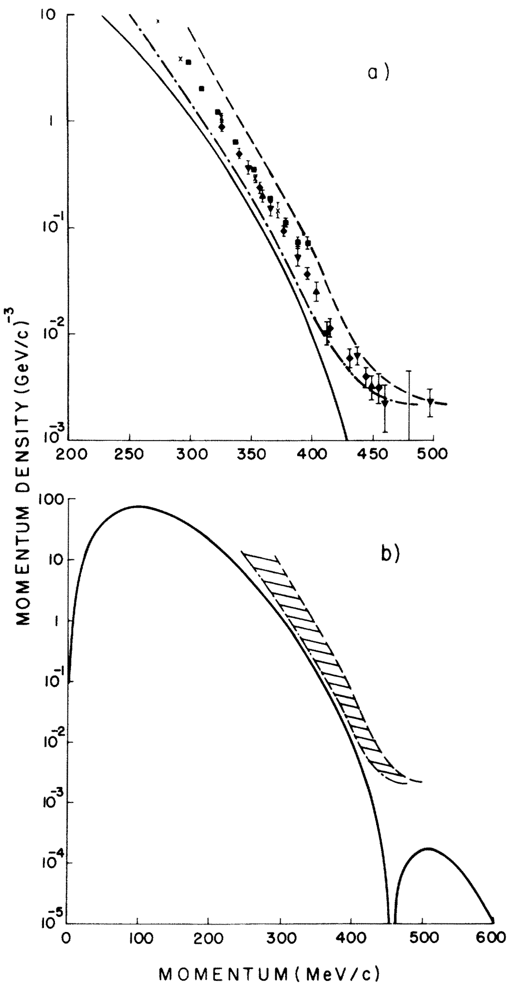

FIG. 1. The experimental $1p_{1/2}$ momentum distribution for ^{16}O ($E_\gamma = 60$ MeV, ■; 80 MeV, ♦; 95 MeV, ▲; 100 MeV, ▼; 40, 50, 70, 90, 105 MeV, 45°, X). The distributions for $V_0 = 18$ and 36 MeV are shown as -·-·-· and -----, respectively. The Elton-Swift momentum distribution is shown as ——.

make up the imbalance between the momenta of the incoming photon and outgoing proton, and the results shown in Fig. 1(a) can be thought of as the empirical probability distribution of this momentum supplied by the nucleus. However, at the high momenta sampled by the present (γ, p) measurements, it is not clear that this distribution can be interpreted as the momentum distribution of the bound proton in its shell model orbit, since some contribution to the cross section is expected to arise through strong two-body residual interactions. The results of the present approximate analysis certainly deviate from the Elton-Swift $1p_{1/2}$ momentum distribution for ^{16}O shown in Fig. 1.

Since the lowest momenta examined here can also be reached in the quasi-elastic scattering process, it would be useful to compare the results of the two different reactions. Unfortunately, there are no measurements of the ^{16}O$(e, e'p)$ reaction at present. Although suitable overlapping data[2,11,12] are available for ^{12}C, some problems remain to be resolved. In the case of the ^{12}C(γ, p) reaction it is not clear which are the $(1p)^{-1}$ hole states in the ^{11}B residual nucleus. Also, since the kinematic conditions in the (γ, p) and $(e, e'p)$ reactions are rather different, it is important that the corrections for the distortion of the final-state wave function due to the complex optical potential be carried out consistently for both reactions. These corrections are being attempted now, before comparing the ^{12}C momentum distributions.

To summarize, it has proved possible to extract a unique momentum (imbalance) distribution up to momenta of 500 MeV/c from data on the ^{16}O(γ, p) reaction; this distribution deviates from a shell-model distribution, and it would be interesting to see if it is consistent with the measurements of other reactions [e.g., (p, d)] which are also sensitive to the high momentum components in the nucleus.

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