Inclusive Electron Scattering from ^{3}He

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Data on inclusive electron scattering from ^{3}He over a large range of momentum transfer (2–7 fm^{-1}) are presented and compared with a one-nucleon knockout calculation based on a Faddeev spectral function.

At large momentum transfer q, the dominant feature in the inclusive spectrum of electrons inelastically scattered by nuclei is a wide peak resulting from elastic scattering from individual nucleons. Previous experiments have shown that in the small q range explored the quasifree-scattering (QFS) peak is well explained by this one-nucleon knockout model.[1] Systematic experiments on inclusive inelastic scattering could be a valuable source of information on the momentum distribution of the constituents,[2] which for the region of energy loss considered are nucleons. For large q, where the nucleon final-state interaction with the residual nucleus is small, a measure of the average nucleon separation energy also can be obtained. As suggested[3,4] earlier, the contributions from high-momentum components in the ground-state wave function should appear primarily in the wings of the QFS peak. In this paper, we present QFS data covering the q range appropriate for a test of nuclear momentum distributions.

This study has been performed on ^{3}He, a nucleus that is particularly suitable for a comparison between experiment and theory. For the three-body system the Schrödinger equation can be solved through Faddeev or variational techniques. With realistic nucleon-nucleon forces as the basic input, the ground-state wave function can be calculated. Different three-body calculations yield appreciable variation (50%) in the mean kinetic energy of nucleons,[5] mainly because these calculations yield different high-momentum components. If quasielastic scattering yields clean information on the momentum distribution of nucleons, it can provide a test of nuclear force models complementary to the most stringent presently used[6]—the binding energy and the charge form factor.

The experiment was performed at the Stanford Linear Accelerator Center together with a measurement on elastic scattering.[7] Incident energies ranged from 3 to 15 GeV; the typical beam resolution was $<0.2\%$, and the average beam current 15 μA. The scattered electrons were detected at 8° using the 20-GeV spectrometer.[7] To span the QFS region, and in order to eliminate eventual local variations of the multiwire proportional chamber (MWPC) efficiency, overlapping spectra were taken at many magnetic field settings of the spectrometer. At each spectrometer setting the contribution of the Al target windows was measured using an empty target. A liquid hydrogen target was used to calibrate the entire system against the well-known e-p cross sections.

Before the experimental spectra were unfolded for radiative effects,[8,9] the small radiative tail from the elastic peak was subtracted with use of the peaking approximation.[9] The use of the peaking approximation was found to be sufficient as the radiative tail from the elastic peak contributed less than 1% to the experimental cross section in the quasielastic region. The integrals for the radiative corrections due to inelastic scattering require, for every incident energy, knowledge of the cross section $d\sigma/d\Omega d\omega$ for all lower incident energies. To obtain the contributions for the lower incident energies we interpolated and extrapolated the measured response functions along lines of constant excitation energy. This procedure[9] results in uncertainties of the corrected cross sections of approximately 5%.

The experimental data covering the full quasielastic region at six incident energies are shown in Fig. 1. The threshold data at four incident energies are shown in Fig. 2. For clarity the data have been averaged over 10-MeV intervals, although the actual energy resolution was somewhat better. The error bars of the data points include all contributions except the 3% uncertainty in the absolute proton normalization. The uncertainty in the ω scale is ± 5 MeV; the ω scale was verified with use of the elastic peak energy determined in the (coincidence) elastic-scattering experiment.[7]

The results can be discussed in terms of the spectral function[10] $S(\vec{k},E)$ which is the combined probability to find in the nucleus a nucleon of momentum $\vec{k}$ and separation energy E. In the case of ^{3}He, S can be written

$$S(\vec{k},E) = \langle \psi_3{}^i | a_k{}^\dagger \delta(E-(H-E_3)) a_k | \psi_3{}^i\rangle$$
$$= \sum_f |\langle \psi_2{}^f | a_{\vec{k}} | \psi_3{}^i \rangle|^2 \delta(E-(E_2{}^f - E_3)). \quad (1)$$

$\psi_2{}^f$ and $\psi_3{}^i$ are the two- and three-body wave functions, respectively; $a_{\vec{k}}{}^\dagger$ and $a_{\vec{k}}$ are the creation and annihilation operators of nucleons with momentum $\vec{k}$. In the plane-wave impulse approximation the (e,e') cross section can be expressed as

$$\frac{d^2\sigma}{d\omega\, d\Omega} = \sum_N d\vec{k}\, \sigma_{eN}\, dE S_N(|\vec{k}-\vec{q}\,|, E)\delta(E-\omega+E_{\rm rec}+E_p), \quad (2)$$

where σ_{eN} is the cross section for electron-nucleon scattering taken from elastic e-N scattering, and $E_{\rm rec}$ is the energy of the center of mass of the two residual nucleons.

Equation (2) is correct only if the antisymmetrization between initial- and final-state wave function may be neglected. This is the case[11] if the momentum transfer is larger than about twice the Fermi momentum, a condition that is well fulfilled by the present data. Using the plane-wave Born approximation also requires that the effect of the final-state interactions (FST) of the knocked out nucleon is small enough to be reliably corrected for. In an inclusive process, where the fate of the recoil nucleon is disregarded, FSI are of minor importance, in general. This is true in particular for small A and for energies of the knocked out nucleon ($\simeq \omega - \omega_{\rm el}$) larger than ~30 MeV. Under these circumstances the influence of FSI may be accounted for by incorporating an effective momentum[12] for the nucleon determined from an energy-dependent optical potential,[13] V. The effective-momentum approach gives distortion corrections to $d\sigma/d\omega d\Omega$ with an accuracy[14] of $\pm 25\%$.

Equation (2) is based on a fully relativistic treatment of the e-N interaction. The bound-nucleon distribution for the momenta < 2.5 fm^{-1} come from a nonrelativistic wave function. This approach is similar to the one of Atwood and West.[15] The present q-ω region does not warrant the simplifications of the bound-state description necessary for a fully relativistic treatment.[16]

The calculation of the QFS cross section was performed using the spectral function of Dieperink *et al.*[17] derived from the Faddeev wave function calculated by Brandenburg, Kim, and Tubis.[18] Both the Faddeev wave function and the two-body wave function were obtained using the Reid softcore nucleon-nucleon interaction. For $q < 5$ fm^{-1} the nucleon form-factor parametrization of Janssens[19] *et al.* was used, while at larger q the scaling (dipole) form factors[20] were employed. The resulting predictions for $\sigma(\omega)$ are shown in Figs. 1 and 2. The uncertainty in the treatment of re-

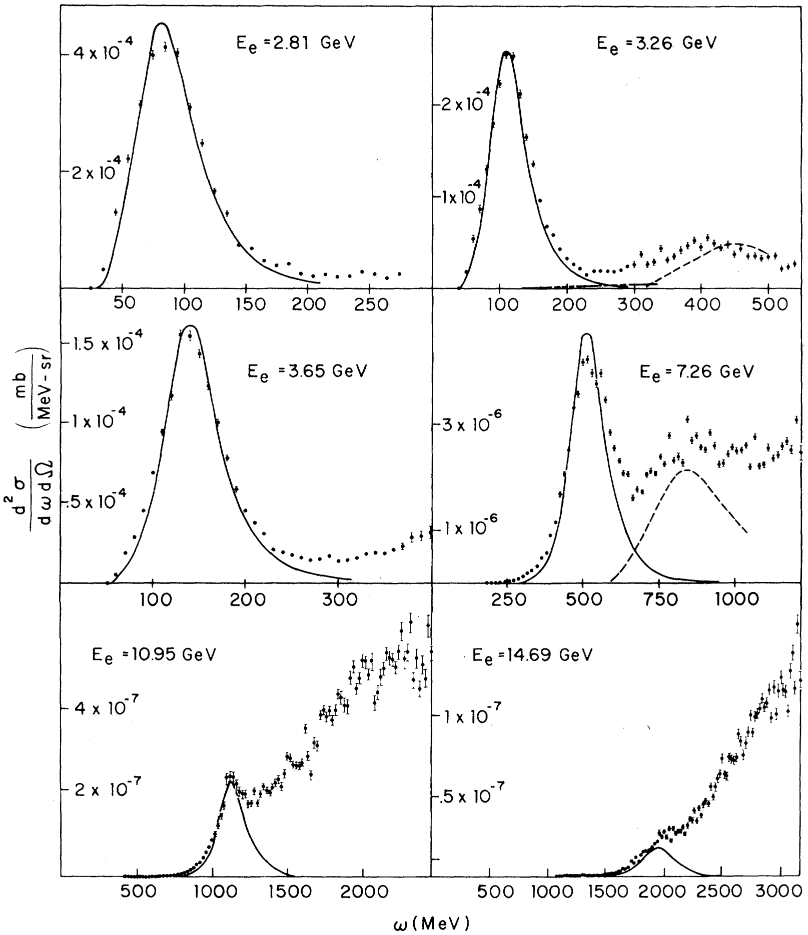

FIG. 1. Inclusive cross sections for $\theta = 8°$ compared with QFS calculation based on Faddeev wave function. The dashed line is the contribution due to $\Delta(1236)$ excitation (Ref. 21), the broken-dash line is the meson-exchange current contribution (Ref. 22).

coil-nucleon FSI is estimated by performing calculations (shown in Fig. 2) for $V' = 0.75$ V. For selected energies Fig. 1 also shows calculations for contributions of other processes to the inclusive spectrum. The dashed curve is the predominantly transverse contribution due to $\Delta(1236)$ excitation as calculated by Do Dang.[21] The broken-dashed curve is the contribution from meson-exchange currents as calculated by Donnelly *et al.*[22] and includes the diagrams of pionic current and pair and intermediate-N^* excitation. The cross sections for coherent π production calculated by Borie[23] are too small to be visible in Figs. 1 and 2.

From the comparison between experiment and Faddeev calculation we see that over the main quasielastic peak the agreement is very good. This shows that over a very large range of momentum transfer we correctly understand the basic reaction mechanism. It also indicates that the part of the ^{3}He momentum distribution containing most of the strength, the region for $k < 1$ fm^{-1}, is correctly predicted by Faddeev theory. The high-energy loss tail of the QFS peak is less well reproduced, as is the case[24,25] for heavier nuclei and lower q; an interpretation of these deviations shall not be attempted here because of the complications introduced by the additional reaction mechanisms contributing in this region of ω.

At "low" ω ($\omega - \omega_{el} < 200$ MeV) and large q, we observe that the calculation systematically underestimates the cross section (Fig. 2). These deviations are much larger than shortcoming in the approximate treatment of the final state employed. Given the fact that in this kinematical region mainly the large-$\vec{k}$ components contribute, it may be reasonable to assign these deviations to a lack of high-momentum components ($k > 2$ fm^{-1}) in the

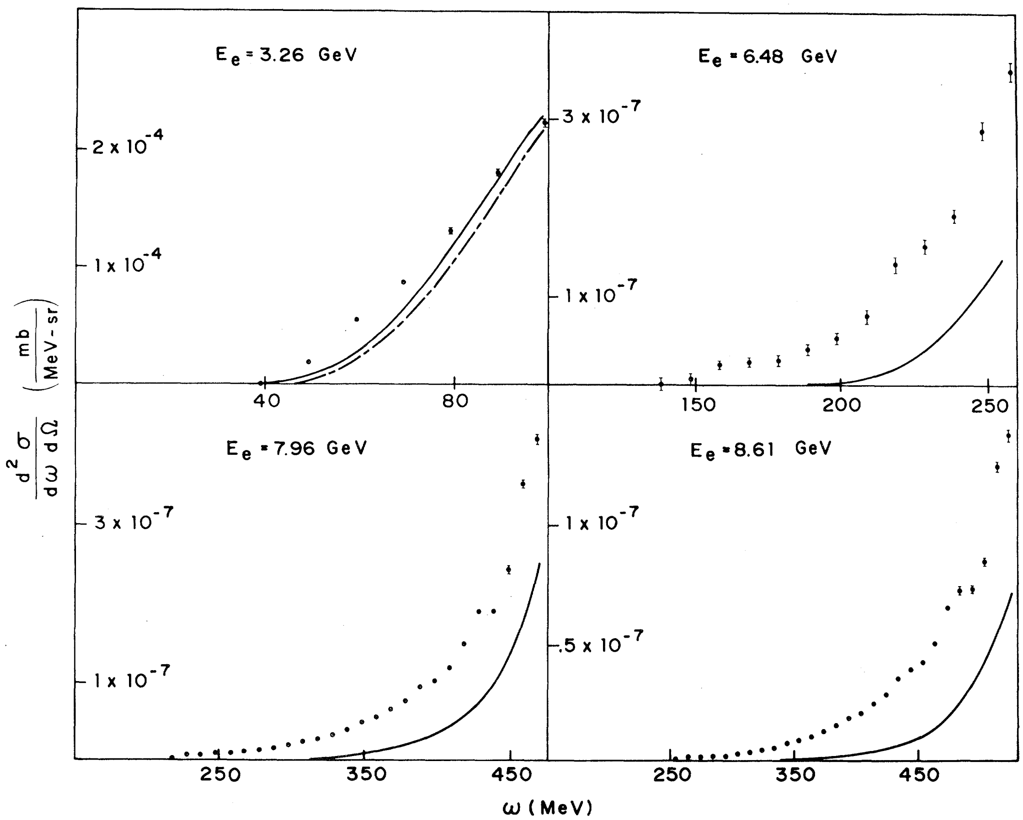

FIG. 2. Threshold inclusive cross sections for $\theta = 8°$ compared with QFS calculation. Dashed line at 3.26 GeV is the Faddeev calculation for $V' = 0.75V$; at larger energy it coincides with the solid curves.

spectral function.

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