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Deep-Inelastic Electron Scattering from ^{12}C

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A systematic study of the deep-inelastic electron-scattering response function of ^{12}C has been carried out at scattering angles of 60° and 130° and electron energies between 160 and 520 MeV. A pronounced transverse strength, the origin of which is not understood, is found in the region between the quasielastic and the N peak.

Quasielastic electron scattering, which corresponds to the incoherent scattering of the electrons by individual nucleons within the nucleus, provides information on average kinetic and separation energies of nucleons. Previous experiments performed on several nuclei have shown that the quasielastic peak can be well fitted by a one-nucleon–knockout model.[1-3] However, it has been observed that the cross sections at large energy loss cannot be explained by this process, even if coherent pion production and N^* excitation are accounted for. Although the results of $(e, e'p)$ coincidence experiments on medium-size nuclei are in good agreement with the one-nucleon-knockout model, they imply a large discrepancy in a theoretical energy-weighted sum rule.[4,5] This deviation could be related to strength in a kinematical region not covered by the $(e, e'p)$ experiments, but appearing at large energy loss in a single-arm experiment. There is, therefore, a compelling need for a systematic experimental study of the deep-inelastic electron-scattering processes.

Such a detailed study on ^{12}C has been performed using the Saclay electron linear accelerator and the electron scattering facility of the HE1 end station.[6,7] The electron incident energy ranged from 160 to 520 MeV with 40-MeV intervals. In order to separate the longitudinal and transverse parts of the response function, data were collected at two scattering angles of 60° and 130°. The scattered electrons were detected using a set of two multiwire proportional chambers associated with plastic scintillators and Čerenkov counters. The very large momentum acceptance ($\Delta p/p = 36\%$) of the "600" spectrometer allowed us to obtain data of high statistical accuracy at scattered-electron energy bins as finely spaced as 1 MeV.

At the higher incident energies, pion contamination resulting from pion electroproduction posed a serious problem. For these runs, the normal Lucite Čerenkov detectors in the spectrometer focal plane were replaced by specially designed silica aerogel Čerenkov counters.[8] This material has a refractive index of ~1.06 and provides a rejection of pions with momenta less than 400 MeV/c. The efficiency of the aerogel detectors was found to be $(95 \pm 1)\%$ for the detection of electrons over the range of momenta used in the experiment. For each incident energy the absolute normalization of the data was obtained by comparing the measured elastic peak at 60° to the well-known ^{12}C elastic-electron-scattering cross section.[9] At the present time, our confidence in the absolute cross-section determination is about ±7%.

The experimental spectra were unfolded for radiative effects using the basic technique of Mo and Tsai[10] modified to include the effects of multiple photon emission.[11] The integrals for the radiative corrections at one incident energy require knowledge of the cross section, $d^2\sigma/d\Omega\, d\omega$, for all lower incident energies. To obtain the contributions for the intermediate values of E_0, we interpolated the measured response functions along lines of constant energy loss. The targets, used in transmission geometry, were less than 0.005 radiation length thick. The radiative tail of the elastic peak, important only for the lower incident energies, was subtracted from the measured data. The tail was computed using the full peaking-plus-background calculation of Maximon and Isabelle[12] with the additional use of second-Born-approximation corrections.[13] The error bars in the figures reflect both the statistical uncertainties and the contribution from the radiative corrections themselves (~3 % of the correction integrals).

The experimental data at eight incident energies and the two scattering angles are plotted in Figs. 1 ($\theta = 60°$) and 2 ($\theta = 130°$). The response function $R(E_0, \omega)$ is defined for each incident energy E_0 and for each excitation energy ω as the ratio of the experimental cross section to the

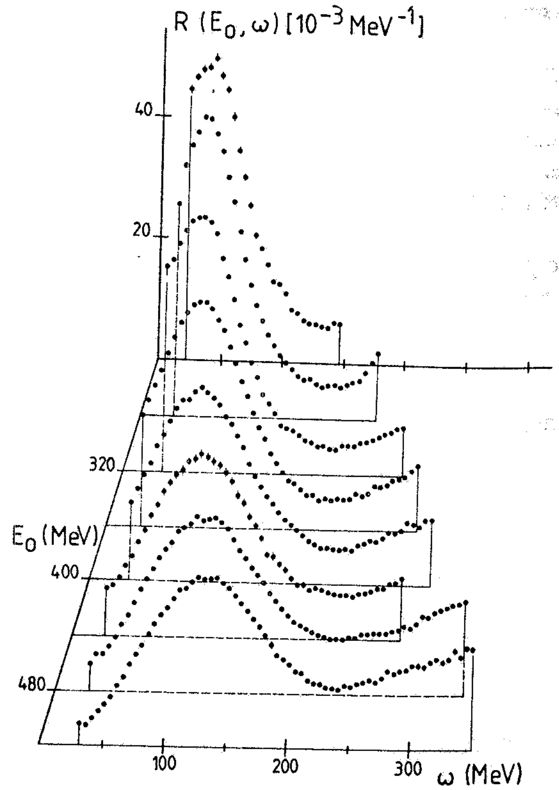

FIG. 1. Inelastic response function for ^{12}C at 60° and electron incident energies between 240 MeV (topmost curve) and 520 MeV in steps of 40 MeV. Where not shown, the error bar is smaller than the dot.

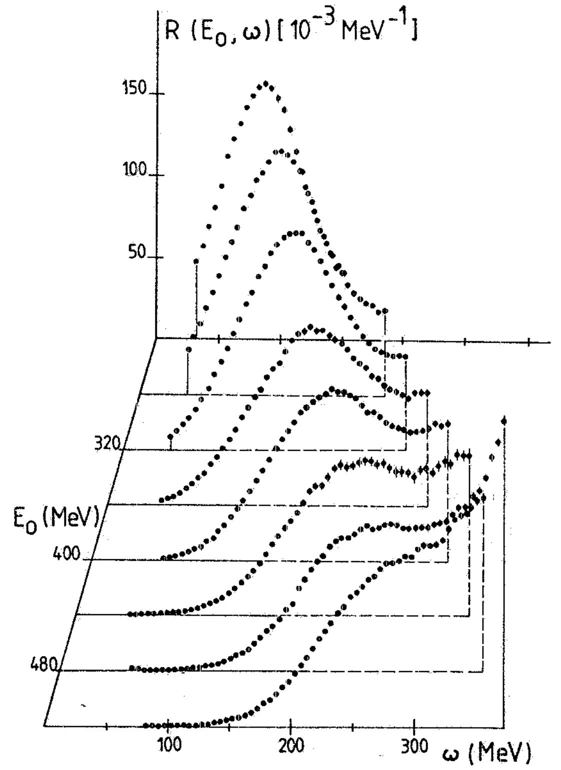

FIG. 2. Inelastic response function for ^{12}C, as in Fig. 1 but for 130°.

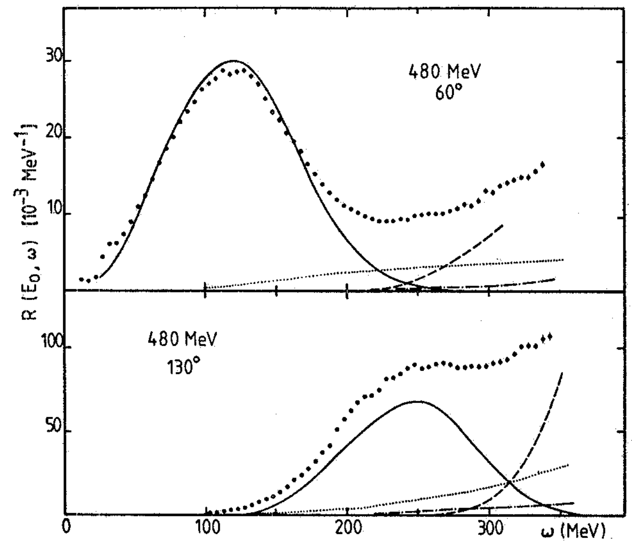

FIG. 3. Response function for ^{12}C compared to a calculation for one-nucleon–knockout process (solid line), coherent pion production (dash-dot line) (Ref. 16), Δ excitation (dashed line) (Ref. 17), and meson-exchange-current contribution (dotted line) (Ref. 19).

proton Mott cross section for E_0 and θ. For clarity the data have been averaged over 5-MeV intervals, although the experimental energy resolution is approximately 1 MeV. For the same reason the elastic peak as well as the discrete excited levels have been omitted. The two lowest-energy spectra are not shown and were used only for radiative corrections.

The experimental response functions for both scattering angles at 480-MeV incident energy are presented in Fig. 3. They are compared with the results of a one-nucleon–knockout calculation,[3,14] using proton momentum and separation-energy distributions derived from the spectral function measured in $(e, e'p)$ experiments.[5] For the small contribution by the neutrons, the same spectral function was assumed. Free-nucleon form factors are used, with a q^2 dependence corresponding to the parametrization made by Janssens *et al.*[15] This calculation is expected to be valid when the final-state interaction of the proton is small, i.e., once ω is larger than about 40 MeV.

Figure 3 also shows calculations for contributions of other processes to the electron-scattering spectrum. The dashed-dotted curve corresponds to coherent pion electroproduction calculated by Borie.[16] This contribution clearly is very small. At large ω, an important, mostly transverse contribution due to Δ(1236) excitation is expected. The dashed curve shows results from a calculation of Do Dang.[17] It employs a Δ-nucleus potential of 40-MeV depth, and assumes that the free Δ width is not modified by the nuclear medium. For a weaker Δ-nucleus final-state interaction, the Δ contribution would be shifted to larger ω. Similar calculations reproduce correctly the Δ excitation cross section at larger ω.[17,18]

From the above comparison between experiment and calculation we clearly see that an additional reaction mechanism is needed to provide strength in the region of the dip between quasielastic and Δ peaks. One likely mechanism concerns the two-nucleon emission not explicitly accounted for in the calculations shown. The contribution of the two-nucleon emission based on the familiar meson-exchange-current–type diagrams has been shown[19] to shift a fraction of the strength of the Δ peak into the dip region. This contribution is of transverse nature, in agreement with what we find experimentally. The calculations of Ref. 19 for both scattering angles and 480 MeV incident energy are shown as dotted curves in Fig. 3.

The contribution of two-nucleon emission clearly goes in the right direction, but seems to be too small. We therefore tend to conclude that a yet unknown mechanism is responsible for the pronounced strength between quasielastic and Δ peaks systematically observed in this experiment.

In the above discussion, we have limited ourselves to the dip region. The quantitative interpretation of the entire longitudinal and transverse response function—a quantity for which systematical experimental information hardly exists in the litterature—will be considered elsewhere.

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Observation of Pair Splittings in the Autoionization Spectrum of Ba

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Using a three-step laser-excitation process we have selectively excited each of the four autoionizing $(6p_j, 20s_{1/2})_J$ states of barium although the $(6p_j, 20s_{1/2})_{j\pm 1/2}$ pairs are separated by less than their autoionization linewidth. The energy and linewidth of each of the states have been measured. The $(6p_{1/2}, 20s_{1/2})_1$ state has an anomalous width which implies that it autoionizes primarily into excited $Ba^+(6p_{1/2})$ ions.

We report, to our knowledge, the first experimental resolution of pair splittings which are smaller than the autoionization linewidths in the autoionization spectrum of an atom. Specifically, we have measured the energies and linewidths of all four components belonging to the $(6p_j, 20s_{1/2})_J$ configuration in Ba. Previously, autoionizing states have been observed by single-photon vacuum-ultraviolet (vuv) absorption spectroscopy[1]; however, for alkaline-earth atoms, that technique is limited to only those states with a total angular momentum of 1. In a previous Letter,[2] we reported a three-step laser technique for populating autoionizing states of the $5p_j,ns$ configuration in strontium; however, only the gross splitting due to the $Sr^+(5p)$ fine structure was resolved. In the experiments reported here, we have made a significant refinement of our previous three-photon excitation scheme by using polarization techniques to force selective excitation of each individual J state, including the $J=0$ and 2 states which are inaccessible to single-photon vuv absorption studies. We have been able to measure the splittings between the $J=j+\frac{1}{2}$ state