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HIGH ENERGY ELECTRON SCATTERING ON ${}^6\text{Li}$ AND ${}^{12}\text{C}$ AS AN
INCOHERENT SUPERPOSITION OF SINGLE NUCLEON PROCESSES

by

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High energy electro-excitation cross sections on ${}^6\text{Li}$ and ${}^{12}\text{C}$ in the region of the first nucleon resonance are compared with calculations in the impulse approximation. It is shown that the ${}^6\text{Li}$ and ${}^{12}\text{C}$ cross sections can be reproduced by an incoherent superposition of nucleon structure functions for $0.2 < Q^2 < 0.4 \text{ GeV}^2$ and primary energies in the GeV range.

The influence of nuclear matter on the nucleon resonances has been discussed in several papers [1]. An unexpected experimental result is reported in refs. [2] and [3], where the cross section per nucleon for the Δ_{33} -electro-excitation in the nuclei ${}^6\text{Li}$ and ${}^{12}\text{C}$ was observed to be significantly smaller than for free nucleons. This appears to be surprising, since the electron is expected to interact with single nucleons only, due to the short wave length of the transferred virtual photon in the kinematic region $0.2 < Q^2 < 0.4 \text{ GeV}^2$ covered by these experiments.

This paper presents a reanalysis of the data of ref. [2] using a method developed in the course of our study of deep inelastic electron nucleus scattering (invariant mass $W > 2 \text{ GeV}$) [4] necessitating knowledge of the cross sections in the resonance region. The method used is similar to that of Atwood and West [5], but is generalized to heavier nuclei.

The basic assumptions are:

- (i) The one photon exchange approximation holds also for electron scattering on complex nuclei.
- (ii) The electron interacts with only one nucleon in the nucleus. The other nucleons remain unaffected.
(Impulse approximation)
- (iii) The momentum distributions of the bound nucleons are described by the nuclear shell model.
- (iv) The structure functions for free and bound nucleon are identical.

These assumptions are the same as used in ref. [2]. Our analysis, however, differs from their method particularly in the concept of handling the Fermi motion. Instead of folding the nucleon cross sections with the Fermi motion, our procedure takes into account that only the hadron vertex is influenced by the Fermi motion, whereas the lepton vertex remains unaffected. The other main difference in the analysis lies in the description of the elementary processes. We describe the nuclear cross sections in a phenomenological manner, where we have fixed the parameters as far as possible. The authors of ref. [2] used a somewhat artificial partitioning of the cross sections with several parameters adjusted in the final fitting procedure.

In the one photon exchange approximation the twofold differential cross section for electron nucleon scattering is usually written as:

$$\sigma = \frac{d^2\sigma}{dE d\Omega} = \sigma_{\text{Mott}} (W_2(Q^2, \nu) + 2 W_1(Q^2, \nu) \tan^2(\theta_e/2)) \quad (1)$$

Here θ_e is the electron scattering angle, W_1 and W_2 are the structure functions of the nucleon, Q^2 is the four momentum transfer ($Q^2 > 0$) and ν is the energy transfer to the hadronic system.

Since the one photon exchange approximation has also been proved valid for complex nuclei [6], the cross section for inclusive electron nucleus scattering can be correspondingly factorized:

$$\sigma_A = \frac{d^2\sigma_A}{dE d\Omega} = \sigma_{\text{Mott}} (W_2^A(Q^2, \nu) + 2 W_1^A(Q^2, \nu) \tan^2(\theta_e/2)) \quad (2)$$

The structure functions W_1^A and W_2^A of the nucleus with mass number A are gained by folding the nucleon structure functions with the momentum distribution of the interacting nucleon while Q^2 is fixed. It turns out that the structure function W_1^A of the nucleus is a function of both W_1 and W_2 of the free nucleons, whereas W_2^A depends only on W_2 . The functional dependence reflects the kinematics of the scattering process including the Fermi motion and binding energy of the scattering nucleon. The contributions of the different shells to the nuclear structure functions W_1^A and W_2^A are calculated separately and summed according to the occupation numbers of the different shells. The complete deduction of W_1^A and W_2^A is given in the basic form for the deuteron case in ref. [5] and in detail for complex nuclei in ref. [7].

For the calculations we took an empirical parametrization of the nucleon structure functions, whereby it is convenient to separate the nuclear cross section into two parts, namely the quasielastic and the inelastic contribution.

For the quasielastic part of the nuclear structure functions we used nucleon structure functions taken from the Rosenbluth formula with the electric and magnetic formfactors of the nucleons given by the scaling law and the dipole fit.

An equivalent parametrization of the inelastic electron nucleon scattering does not exist. Therefore we used W_1 and W_2 extracted from measured inelastic cross sections of protons and deuterons [8]. In order to cover the region below $Q^2 = 0.15 \text{ GeV}^2$, photoproduction data were included [9]. The structure functions for protons and neutrons were gained in the kinematic region of $Q^2 < 1.5 \text{ GeV}^2$ and for invariant masses $W < 1.8 \text{ GeV}$ by interpolating the experimental data along lines of constant W . The quality of the interpolations was checked to reproduce several independent measurements within the kinematic region defined above [7].

The procedure outlined here was applied to obtain the quasi-elastic and the inelastic parts of W_1^A and W_2^A for the nuclei ${}^6\text{Li}$ and ${}^{12}\text{C}$ within the kinematic region $Q^2 \leq 1.5 \text{ GeV}^2$ and $\nu \leq 1.7 \text{ GeV}$. The quantities used for these calculations are listed in table 1. Using the values of W_1^A and W_2^A , the cross sections for quasielastic and for inelastic scattering, $\sigma_A^{\text{qu}}^{\text{el}}$ and σ_A^{inel} respectively, were computed separately according to eq.(2).

For the comparison with the measured cross section, radiative processes have to be considered. Since the nuclear cross sections have been calculated for the whole kinematic region, the contributions of the radiative processes to the experimental cross section can be directly calculated. This was done by applying the formulas of Mo and Tsai [10]. The radiative tail of the elastic electron nucleus scattering has been estimated to be negligible for $Q^2 > 0.2 \text{ GeV}^2$. In order to account for the experimental resolution $\text{FWHM} = 0.025 \text{ GeV}$, the calculated cross sections were smeared by a Gaussian distribution. A detailed description of the measurements is given in refs. [11] and [12].

The experimental cross section of the nucleus is parametrized as the sum of the two calculated contributions $\sigma_A^{\text{qu}}^{\text{el}}$ and σ_A^{inel} ,

$$\sigma_A^{\text{exp}} = C \left| \frac{A_{\text{eff}}^{\text{qu}}}{A} \sigma_A^{\text{qu}} + \frac{A_{\text{eff}}^{\text{inel}}}{A} \sigma_A^{\text{inel}} \right|$$

For the quasielastic scattering the impulse approximation is well established [5,13]. Since no Pauli blocking is expected for $Q^2 > 0.2 \text{ GeV}^2$ the effective number of nucleons for quasielastic scattering $A_{\text{eff}}^{\text{qu}}$ is set equal to A . The only parameters left are C and $A_{\text{eff}}^{\text{inel}}/A$. The factor C accounts for systematic errors [14] in the absolute experimental cross sections and $A_{\text{eff}}^{\text{inel}}/A$ is a measure of the validity of the underlying model to be tested against the experiment. It should be unity if inelastic electron nucleus scattering, as in the case of quasielastic scattering, can be described as an incoherent superposition of single nucleon processes.

Fig. (1) compares our results with the experimental data of refs. [11] and [12]. The calculations reproduce the width and the shift of the peaks originating from the Fermi motion and binding energies of the nucleons. For ${}^6\text{Li}$ the general agreement is good and no significant deviations from the experimental spectra are observed. The ${}^{12}\text{C}$ data differ from the calculations in the region of low invariant mass, and the minimum between the quasielastic and inelastic scattering is more pronounced in the calculations. This is caused by the fact that the experimental spectra of ${}^{12}\text{C}$ are smoothed with Gaussian distributions [12].

The values of $A_{\text{eff}}^{\text{inel}}/A$ obtained from the fit are listed in table 2 and are plotted versus $Q_{\Delta_{33}}^2$ in fig. (2). The mean values of $A_{\text{eff}}^{\text{inel}}/A$ are 0.97 and 1.01 for ${}^6\text{Li}$ and ${}^{12}\text{C}$ respectively. With an estimated uncertainty of at least 10 % for the extracted values (due to the uncertainties in the input data, particularly the neutron cross sections), we find no significant deviation of the effective mass number $A_{\text{eff}}^{\text{inel}}$ from the number of nucleons A composing the nuclei.

In summary, for ${}^6\text{Li}$ and ${}^{12}\text{C}$ in the kinematic region $W < 1.5 \text{ GeV}$ and $0.2 < Q^2 < 0.4 \text{ GeV}^2$ for primary energies in the GeV range, the experimental cross sections are described in the impulse approximation by folding the nucleon structure function with the momentum distributions of the bound nucleons. A suppression of the electro-excitation in the Δ_3 -region cannot be observed.

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Table 1

Quantities used for the calculations

nucleus	shell	binding energy 15 GeV	reso- lution FWHM GeV	radiation in front of the target times 10 ³	length behind center
⁶ Li	s 1/2	0.0213	0.025	3.104	4.072
	p 3/2	0.0049			
¹² C	s 1/2	0.030	0.025	6.64	9.149
	p 3/2	0.017			

Table 2

Values for $A_{\text{eff}}^{\text{inel}}/A$

target nucleus	E_1 (GeV)	θ_e	$Q_{\Delta_{33}}$ (GeV ²)	$A_{\text{eff}}^{\text{inel}}/A$
${}^6\text{Li}$	2.50	12.0	0.222	0.97
${}^6\text{Li}$	2.70	13.8	0.348	0.97
${}^6\text{Li}$	2.70	15.0	0.395	0.96
${}^{12}\text{C}$	2.0	15.0	0.210	1.01
${}^{12}\text{C}$	2.50	15.0	0.337	1.02
${}^{12}\text{C}$	2.70	15.0	0.395	1.01

FIGURE CAPTIONS

Fig. 1 Electron scattering cross section versus the invariant mass W for ${}^6\text{Li}$ and ${}^{12}\text{C}$ target nuclei. The long and short dashed lines represent the calculations for the quasielastic and inelastic scattering respectively. The solid line is the sum of both. The arrows indicate the masses of the proton and the Δ_{33} resonance.

Fig. 2 $A_{\text{eff}}^{\text{inel}}/A$ for ${}^6\text{Li}$ (o) and ${}^{12}\text{C}$ (●) versus Q^2 (GeV^2) at $W = 1.236$ GeV.

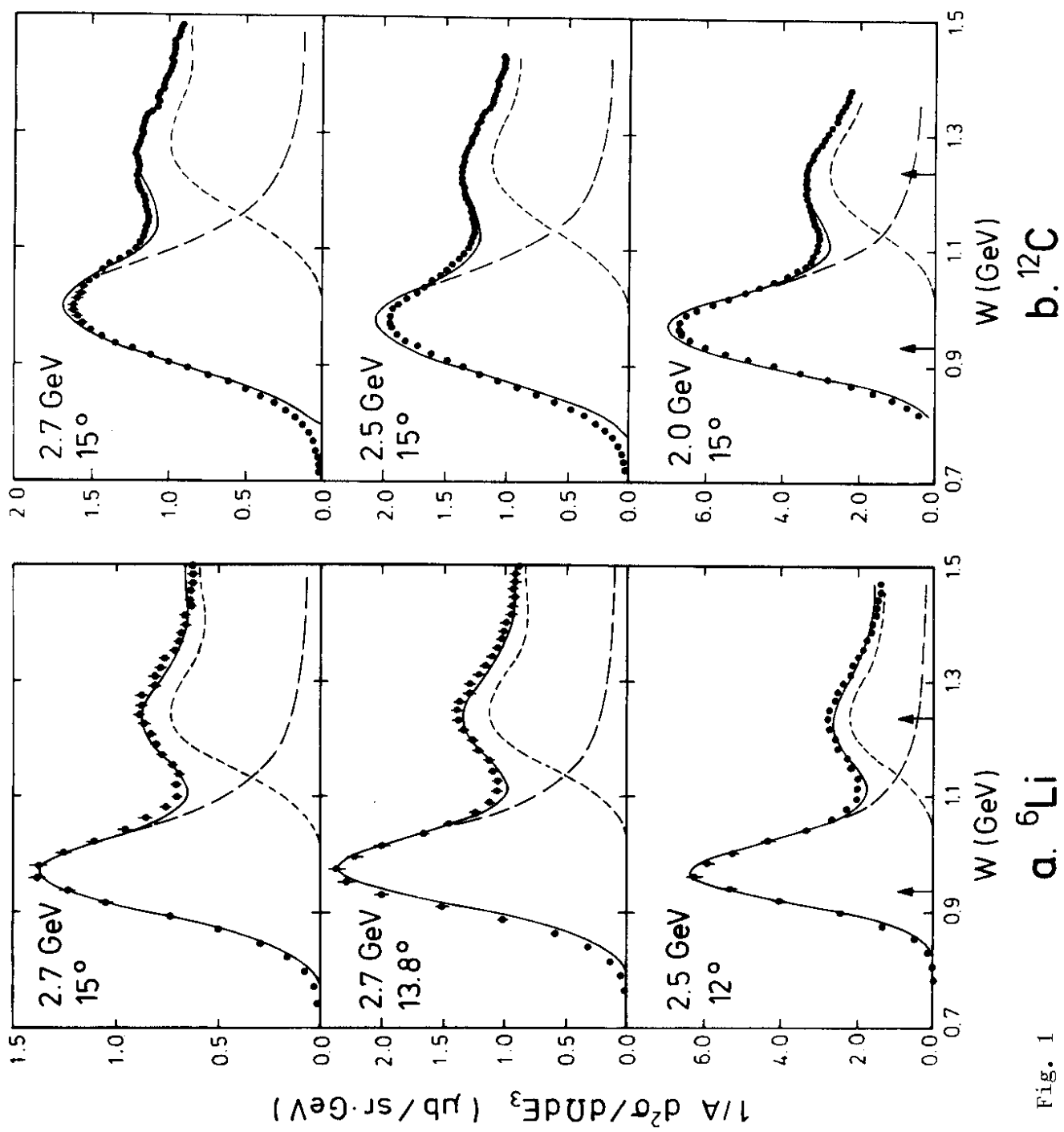


Fig. 1

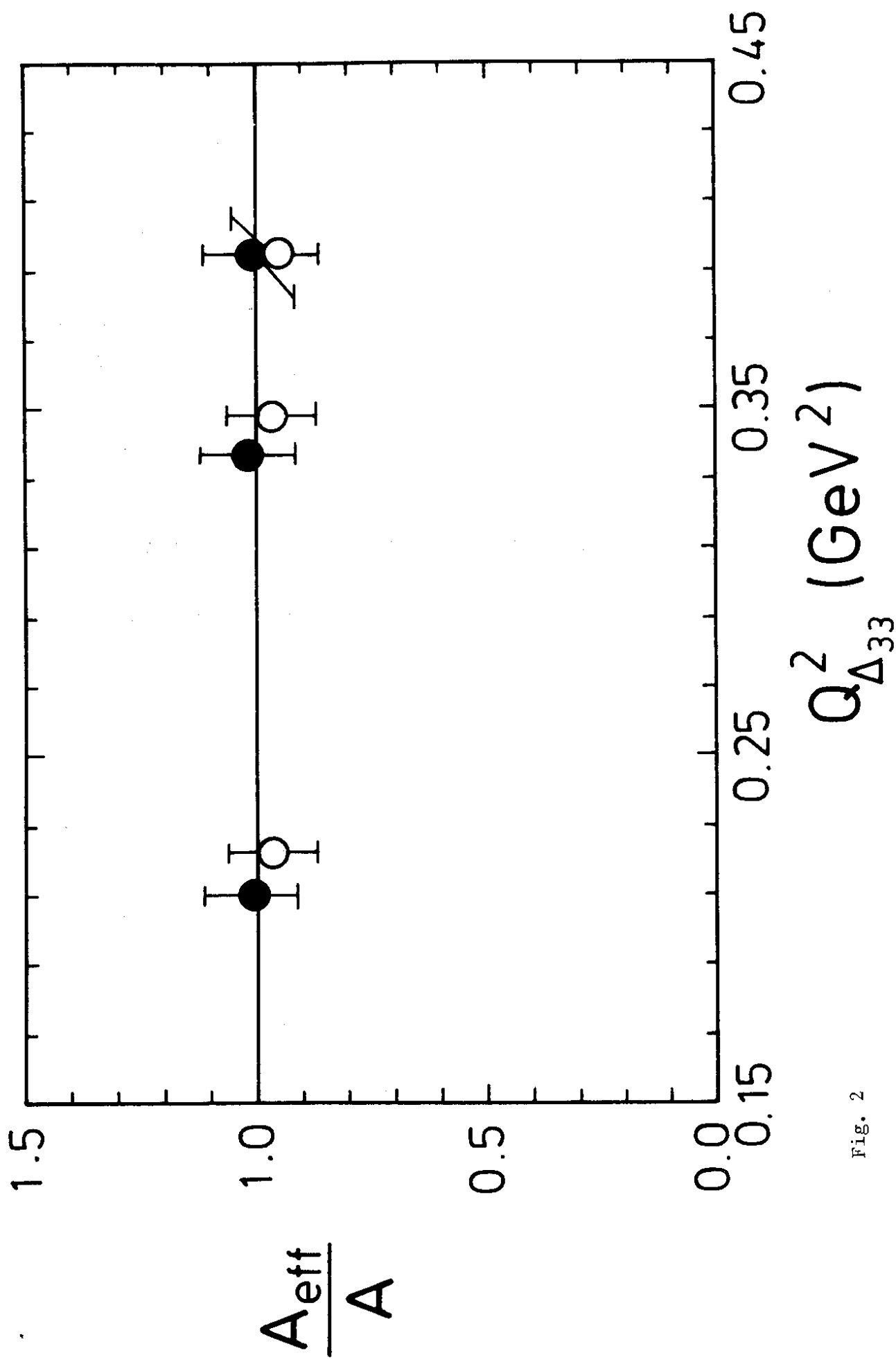


Fig. 2