SLAC-PUB-1184
(TH)
February 1973

# FIXED POLE ANALYSIS OF THE DEUTERON COMPTON AMPLITUDE*

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## ABSTRACT

Using standard finite energy sum rules we evaluate the $\alpha$=0, energy independent real part of Compton deuteron scattering. Unlike the proton and neutron cases, the result is not consistent with the Thomson limit.

(Submitted to Phys. Rev.)

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*Work supported by the U. S. Atomic Energy Commission.

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## I. INTRODUCTION

The high energy behavior of Compton scattering has been of particular interest in atomic, nuclear and particle physics alike. Gell-Mann, Goldberger, and Thirring[1] considered the problem for atomic and nuclear systems. They conjectured that at high enough energies, the coherent Compton scattering amplitude on a bound electron, $f_B(\nu)$, would approach $f_{free} = - \alpha/m_e$.[2] Years later, Goldberger and Low (G.L.)[3] actually performed the calculation for an electron bound to an infinitely massive force center, and found that, in the high energy regime, the scattering amplitude is real and energy independent but that its value may differ considerably from the free electron value, particularly in the strong coupling limit.

A general form, for composite systems of pointlike constituents, which incorporates the possible subtleties of binding effects, has recently been discussed by Brodsky, Close and Gunion (B.C.G).[4] They find that the forward Compton amplitude on an atom has the high energy limit

$$f_{at}(\nu) \xrightarrow[\nu >> B.E.]{} -\frac{Z\alpha}{M_{at}} \int_0^1 \frac{f_e(x)}{x}\, dx = \frac{-Z\alpha}{m_{eff}} \qquad (1)$$

where $f_e(x)$ is the normalized, $\int_0^1 f_e(x)\, dx = 1$, probability distribution for finding an electron with momentum $x\vec{P}$ in an atom moving with momentum $\vec{P}$ in the limit $|\vec{P}| \to \infty$, $\langle \frac{1}{x M_{at}} \rangle \equiv \frac{1}{m_{eff}}$ plays the role of an effective electron mass. The high energy limit arises from the coherent sum of the "seagull" terms for the individual constituents.[5]

These same qualitative features apply to the high energy behavior of Compton scattering on composite hadrons despite the additional complications of Regge behavior. That is, the constituent "seagulls" still give rise to a constant real part.[4]

A direct evaluation of the $\alpha$=0 contribution to the real part of on-shell proton Compton scattering[6] yielded a result consistent in magnitude and sign with the Thomson limit.

$$f_1^{\alpha=0}(\infty) = f_1(0) = -\frac{\alpha}{M_p} \quad , \tag{2}$$

i.e., the proton behaves like a pointlike object as far as the $\alpha$=0 "fixed pole" behavior is concerned.

More recently, it has been shown[7] that a careful extraction of the total neutron photoabsorption cross section, in combination with the standard finite energy sum rules (FESR) techniques leads us to believe that an $\alpha$=0 term may not be required in neutron Compton scattering (in agreement with the Thomson limit for the neutron).

These results are particularly curious in light of the fact that complications due to Regge behavior have to be considered. The correct prescription for evaluating the $\alpha$=0 contribution is obtained after the leading $\alpha>0$, Regge behavior has been substracted. The $\alpha$=0 term is given by:

$$C = f_1^{\alpha=0} = -\frac{e^2}{4\pi M} \sum_i \lambda_i^2 \int_0^\infty \left\{ \frac{f_i(x)}{x} \, \theta(1-x) - \sum_{\alpha>0} \frac{\gamma_\alpha^i}{x^{\alpha+1}} \right\} dx \tag{3}$$

where $f_i$ is the ith parton's infinite momentum frame distribution function, which is related to the deep inelastic structure function, using the conventional momentum, by $\nu W_2 \left(\omega = -q^2/2M\nu\right) = e^2 \sum_i \lambda_i^2 \, \omega f_i(\omega)$ . Due to the Regge behavior of hadronic amplitudes $f_i(x) \sim \gamma_\alpha^i / x^\alpha$ for small x.

An underlying reason as to why this expression should reduce to the Thomson limit is not apparent.

Given this state of affairs it becomes of interest to see how a composite system of nucleons behaves in regard to the $\alpha$=0 energy independent piece in its Compton amplitude. The deuteron is, of course, the only such system for which adequate data are available. In the weak binding limit, $f_{p,n}(x) \sim \delta(x-1/2)$, one expects (given the phenomenological fact that nucleons behave as if pointlike in their $\alpha$=0 behavior) that

$$C = f_{1(\mathrm{deut})}^{\alpha=0} = -\frac{\alpha}{M_d} \frac{\left(\lambda_p^2 + \lambda_n^2\right)}{1/2} = -3\ \mu\mathrm{b\ GeV} \quad . \tag{4}$$

On the other hand, it is possible that binding effects would be sufficient to give $C = -\alpha/M_d = -1.5\ \mu$b GeV, the deuteron's Thomson limit. The important binding corrections arise primarily from two sources (a) photodesintegration of the deuteron and (b) shadow and Fermi motion effects.

Even at high energies, $\sigma_d \neq \sigma_p + \sigma_n$ as a result of the Glauber and smearing effects.[7,8] It is the purpose of this paper to evaluate the deuteron Compton amplitude, constant real piece ($\alpha$=0 fixed pole) including the above mentioned effects in order to see if a qualitative picture emerges. We shall see that the weak binding result, i.e., C = $-3\ \mu$b GeV appears to be consistent with the data, while the Thomson limit value is not.

## II. ANALYSIS OF THE DATA

The procedure for obtaining the $\alpha$=0 contribution is by now familiar. For the deuteron, care has to be taken that contributions below normal nucleon threshold are included. One has

$$C = f_1^D(\nu=0) - \frac{1}{2\pi^2}\left[\int_0^N \sigma_T^D(\nu)\, d\nu - \left(NA + \frac{N^\alpha}{\alpha} B\right)\right] \tag{5}$$

where a simple power law behavior has been assumed for $\nu > N$

$$\sigma_0(\nu) \sim A + B\, \nu^{\alpha(0)-1} \qquad (6)$$

A and B are the Pomeranchuk and P' trajectory residues respectively. In contrast to the analysis on nucleons we will not assume a priori $\alpha(0) = 1/2$ . The energy dependent nucleon physics corrections could possibly change $\alpha(0)$ from the value observed on free nucleons. We performed fits to the available data[9] using the form given in Eq. (6). The results for A, B, and $\alpha(0)$ for a variety of cutoffs and combinations of data groups are presented in Table I. The errors assigned to the deuteron total cross section in the fitting program included both statistical and averaged systematic errors. For comparison we give in the same table results for fits of the form $a+b/\sqrt{\nu}$ .

One should notice that as the low energy cutoff increases the preferred value of $\alpha(0)$ approaches 1/2. This is a reflection of the fact that above 4 GeV the shadow and smearing corrections become almost energy independent,[7] thus affecting only the Pomeranchuk piece. On the other hand, in the region between 2 and 4 GeV, both corrections show a substantial energy dependence and deviations from the simple form $\sigma \sim a+b/\sqrt{\nu}$ seem to be present as the fitted values of $\alpha(0)$ indicate. The $\chi^2$ minimum is, however, extremely shallow so that the above deviations may not be statistically meaningful. In any case, despite the inherently larger errors in the Regge parameters, the most trustworthy results for the $\alpha$=0 residue will be those for which the data is directly integrated up to 4 GeV and a normal Regge form used thereafter.

In Table II we present the low energy integrals, over the deuteron data, required in Eq. (5); $\int_0^N \sigma_T^D(\nu)\, d\nu$ was evaluated using the $\gamma D \rightarrow p+n$ data up to .150 GeV and the Daresbury data from .265 GeV to N. Between .150 GeV and .265 GeV, two alternatives were used to interpolate the two sets of data.

(a) $\sigma_D(\nu) = 2\sigma_p(\nu)$, i.e., no smearing corrections,

(b) $\sigma_D(\nu) = 2\sigma_p^{smeared}(\nu)$,

where $\sigma_p^{smeared}$ was calculated using a standard Hamada-Johnston deuteron wave function. The true deuteron cross sections may lie between these two limits, the s wave contribution in that region being somewhat larger for neutrons than protons.

It should be pointed out that the $\gamma D \rightarrow p+n$ channel gives $\int_0^{.150} \sigma_T^D(\nu)\, d\nu \sim$ 18.9 $\mu$b GeV, a contribution to

$$f_1^{\alpha=0}(\text{deut}) = -0.95\ \mu\text{b GeV} \quad .$$

Excluding the low cutoff fits with $\alpha$ not $\approx 1/2$ we obtain a range of fixed pole values that lie between -2.2 $\mu$b GeV and -6.6 $\mu$b GeV. Table III presents a complete compilation. The quoted errors, for the fixed $\alpha$=1/2 fits, include those arising from the Regge parameter error matrices; small additional uncertainties are present due to error in the low energy integrals. For the nonlinear three parameter fits, the error matrices were not judged to be meaningful. Although the results are anything but conclusive they suggest a value for C that is larger than the low energy theorem value and perhaps consistent with the proton Thomson limit. Thus the various nuclear binding effects appear to at least partially cancel, leaving a result consistent with the "weak binding limit."[10] A direct measurement of the real part of deuteron Compton scattering would, of course, be preferable to the above analysis and could provide a clue as to possible anomalous behavior of the total photoabsorption cross section at energies above those currently measured.

## FOOTNOTES AND REFERENCES


1. M. Gell-Mann, M. L. Goldberger, and W. Thirring, Phys. Rev. 95, 1612 (1954).

2. Throughout the paper, we will only consider the spin averaged forward scattering amplitude, to lowest order in $\alpha$; to that order the amplitude on a free electron is equal to $-\alpha/m_e$, the Thomson limit.

3. M. L. Goldberger and F. E. Low, Phys. Rev. 176, 1778 (1968).

4. S. Brodsky, F. Close and J. Gunion, Phys. Rev. D5, 1384 (1972), see also S. Brodsky, Report No. SLAC-PUB-1118 (1972), "Atomic physics and quantum electrodynamics in the infinite momentum frame," Presented at the Third International Conference on Atomic and Nuclear Physics, August 7-11, 1972, University of Colorado, Boulder.

5. This is strictly true only in the scalar case; for partons with spin 1/2 the so-called "z graph" is the one that survives at high energies, but this diagram effectively behaves as a seagull when seen in the above described infinite momentum frame. (See B.C.G., Ref. 4.)

6. M. Damashek and F. J. Gilman, Phys. Rev. D1, 1319 (1970); C. A. Dominguez, C. Ferro-Fontan and R. Suaya, Phys. Letters 31B, 365 (1970).

7. C. A. Dominguez, J. Gunion, and R. Suaya, Phys. Rev. D6, 1404 (1972).

8. W. B. Atwood and G. B. West, Report No. SLAC-PUB-1081, submitted to Phys. Rev.

9. J. A. Armstrong et al., Nucl. Phys. B41, 445 (1972); H. Meyer et al., Phys. Letters 33B, 189 (1970); D. O. Caldwell et al., Phys. Rev. Letters 23, 1256 (1970); D. O. Caldwell et al., University of California, Santa

Barbara preprint (September 1972), submitted to Phys. Rev. Photonuclear data index, Report No. NBS 322 (1970) unpublished and references cited therein.

10. It is amusing to notice that this result is again consistent with Harari's argument, in which one can switch off the strong interactions (leaving behind an elementary neutron and proton), since the deuteron becomes unbound in this limit. In this case, the proton and neutron $\alpha$=0 terms are given by their respective Thomson limits, while that of the deuteron is the sum of the two. This picture becomes suspect when one considers the nucleons to be composite systems.

## TABLE CAPTIONS

I. Regge Fits, with $\alpha(0)$ variable and $\alpha(0)$ fixed at 1/2. Errors are only quoted for the last case.

II. Low energy integrals for different cutoffs; we tabulate the integral $\int_0^N \sigma_D(\nu)\, d\nu = I$. The values of I tabulated correspond to the choice $\sigma_D(\nu) = 2\sigma_p(\nu)$ for $0.150 < \nu < 0.265$ GeV. The corresponding values for the choice $\sigma_D(\nu) = 2\sigma_p^{smeared}(\nu)$ $0.150 < \nu < 0.265$ GeV are 5 $\mu$b GeV smaller, when a Hamada-Johnston wave function is used.

III. Fixed pole results, the numbers in the 1st column correspond to the labels in Table I. The error quoted for the two parameter fits, take only into consideration the uncertainties due to the Regge parameters.