DEUTERON PHOTOEFFECT WITH A REPULSIVE CORE *

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RESUMEN

An analytic result is given for the electric dipole contribution to the deuteron photoeffect cross section, for a central Serber force containing an r^{-2} *repulsive core. A comparison between calculations and experiment indicates that for energies greater than 60 Mev other effects like the interaction in the final state and mesonic effects are of more importance than the inclusion of this repulsive core. Sum rule calculations are also discussed.*

Analytic expressions for the cross section for the deuteron photoeffect have been obtained by several authors [1-4] for different assumed shapes of the neutron potential. Recent analysis of Berkeley measurements of proton-proton scattering [5], as well as work by Jastrow [6] and Levy [7], has indicated the importance of a repulsive core

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in the neutron-proton potential. Austern[8] has already calculated the deuteron photo-effect with an infinite repulsive core of radius R, and finds a moderate increase in the cross section in the energy range from 50-150 Mev.

In this paper we shall include the effect of a short range repulsion in the neutron-proton potential, obtaining the cross section in a simple analytic form. As in references 1-4, and 8, we assume a central potential, of Serber character. Further, we neglect mesonic effects which are of great significance above the threshold for meson production.

We generalize the Hulthén wave function, and corresponding potential, by taking the radial wave function $u = r\,\Psi/N$ of the form

$$u(r) = \exp(-\gamma r) - \exp(-\beta' r) - (\beta' - \gamma)\, r \exp(\beta' r) \qquad (1)$$

Substitution into the wave equation gives the potential

$$V(r) = -(\hbar^2/M)(\beta' - \gamma)^2 \left[-1 + (\beta' + \gamma) r\right] \left\{ \exp\left[(\beta' - \gamma) r\right] - 1 - (\beta' - \gamma) r \right\}^{-1} \qquad (2)$$

Here $\gamma = (M\epsilon/\hbar^2)^{1/2}$, while β' is determined from the effective range. The value[9] $r_o(-\epsilon, -\epsilon) = 1.79$ fermis gives

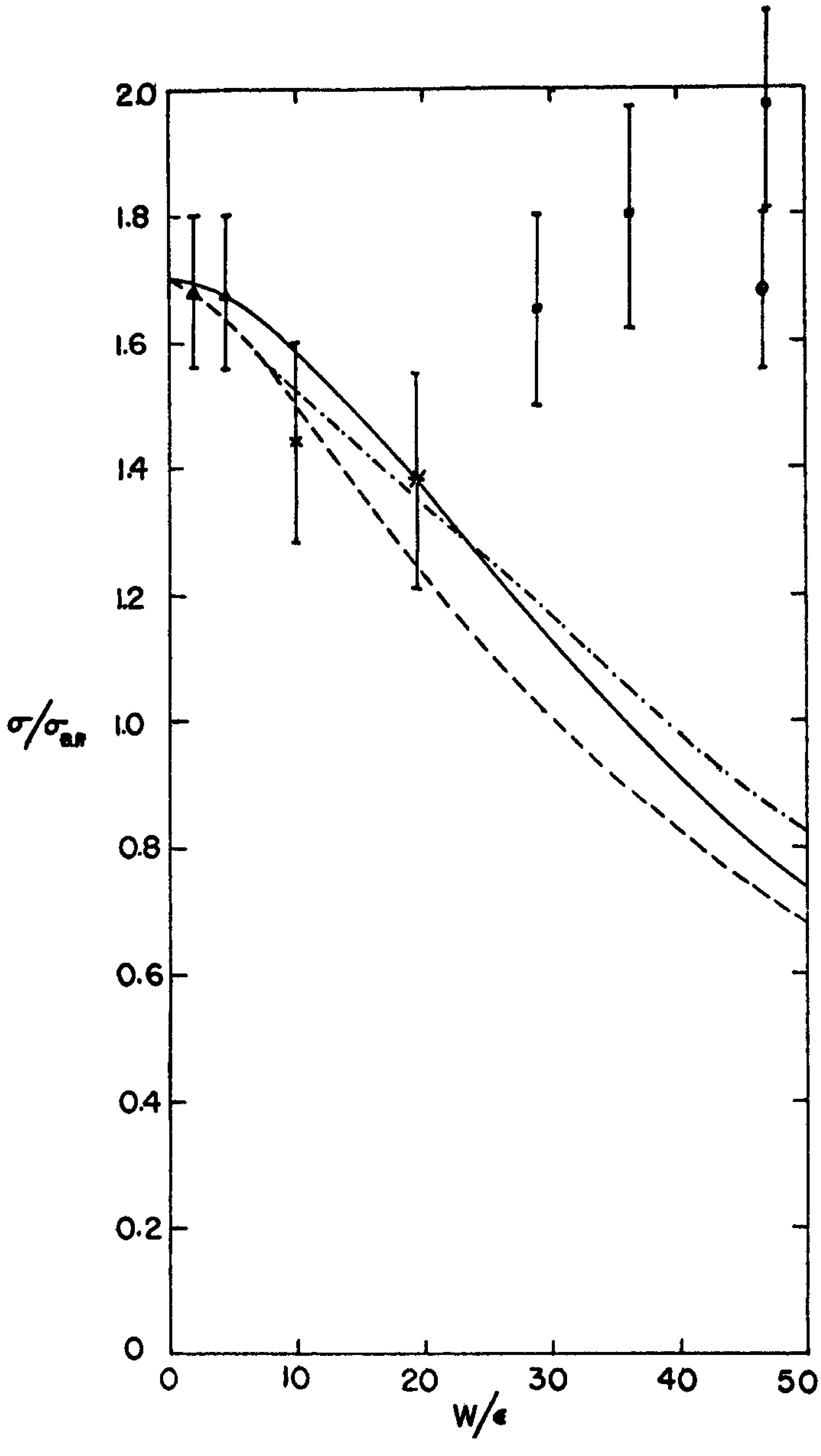
$$\beta' = 10.53\,\gamma = 2.439 \text{ fermis}^{-1} \quad , \qquad (3)$$

The normalization constant N is expressed in terms of r_o:

$$N^2 = \left[2\gamma/(1 - \gamma r_o)\right] \quad . \qquad (4)$$

The potential V changes sign at about 0.38 fermis, being proportional to r^{-2} at small distances; while the wave function u goes as r^2 near the origin.

We represent the outgoing particle by a plane wave. We find the total cross section σ_{RC} for electric dipole photodisintegration relative to the Bethe-Peierls cross section, σ_{BP}:



Cross Sections for the deuteron photoeffect

The ratio of the cross section to the Bethe-Peierls cross section σ_{BP} is plotted against the photon energy W in terms of the binding energy ϵ. The solid curve shows the results of this paper; the dashed curve shows the results for a Hulthén potential (references 2-4), while the dashed-dotted curve shows Austern's results for a repulsive core of radius 0.4 fermis (reference 8). The experimental data are: triangles, Wilkinson et al (reference 10); stars, Allen, (reference 11), squares, Whalin et al. (reference 12); and circle, Keck and Tollestrop, (reference 13).

$$\sigma_{RC}/\sigma_{BP} = (1-\gamma r_o)^{-1}\{1-[(\gamma^2+k^2)^2/(\beta'^2+k^2)^2]- - [4\beta'(\beta'-\gamma)(\gamma^2+k^2)^2/(\beta'^2+k^2)^3]\}^2 \quad . \quad (5)$$

Here the factor $(1-\gamma r_o)^{-1}$ is the usual effective range correction, coming from the normalization; while the first two terms in the square bracket are the result[2-4] for a Hulthén potential. (Note that β for a Hulthén wave function must have a value different from that of β' for a repulsive core wave function).

Figure 1 shows three different calculated cross sections, as well as experimental data[10-13], all given relative to the Bethe-Peierls cross section. The lowest curve is the Hulthén cross section[2-4]. We see that the r^{-2} repulsive core assumed here gives rather similar results to Austern's results[8] for an infinite repulsive core of radius 0.4 fermis. All three calculated curves agree well with experiments up to 20 times the threshold energy ϵ ; but experiments at energies from $30\,\epsilon$ to $50\,\epsilon$ give cross sections much higher than the calculated values. (The discrepancy between calculations and experiment is reduced, but is still significant, if we use Austern's values for a core radius of 0.8 fermis. For example, at a photon energy of $40\,\epsilon$, the three curves shown give σ/σ_{BP} about 0.9; a core radius of 0.8 fermis gives σ/σ_{BP} about 1.3; while the experimental data[12,13] gives σ/σ_{BP} about 1.85). We conclude that present experiments up to energies of $20\,\epsilon$ cannot verify the changes of order 10 per cent in the cross section produced by a repulsive core.

On comparing the results for the E-1 bremsstrahlung weighted cross section ($\sigma_b = \int(\sigma/w)\,dw$) for same values of the effective range $r_o(-\epsilon,-\epsilon) = 1.79\times10^{-13}$ cm, it is found that[14]

$$\frac{\sigma_b \text{ (Repulsive core)}}{\sigma_b \text{ (Hulthén)}} = 1.00$$

In other words the bremsstrahlung weighted cross section is not changed due to the introduction of this repulsive core; but both σ_b (Repulsive Core) and σ_b (Hulthén) are found to be in very good agreement with the experimental value[15] $\sigma_b = 3.7$ mb.

We have also calculated the integrated cross section $\sigma_{int} = \int\sigma\,dw$ for

Hulthén and the present repulsive core wave function. For Hulthén wave function we find

$$\sigma_{int} = \int \sigma\, dw = \frac{\pi^2 e^2 \hbar}{Mc}\left[1 - \frac{2}{3}\,\frac{M(x+y)N^2}{\hbar^2}\int u^* V r^2 u\, dr\right] =$$

$$= \frac{\pi^2 e^2 \hbar}{Mc}\left[1 + \frac{4}{3}\,\frac{(\beta^2/\gamma^2 - 1)(x+y)}{(1-\gamma r_o)}\left\{\frac{2}{(1+\beta/\gamma)^3} - \frac{1}{4(\beta/\gamma)^3}\right\}\right] =$$

$$= 30\ [\ 1 + 0.37\,(x+y)\ ]\quad \text{Mev - mb.}$$

Here x and y are the fractions of the Majorana and Heisenberg type, and $\beta = 5.83\,\gamma$ as determined from the effective range. A similar calculation with the repulsive core wave function used in this paper gives us

$$\sigma_{int} = \int \sigma\, d w =$$

$$= \frac{\pi^2 e^2 \hbar}{Mc}\left[1 + \frac{4}{3}\,\frac{(\beta'/\gamma - 1)^2 (x+y)}{(1-\gamma r_o)}\left\{\frac{4}{(1+\beta'/\gamma)^3} - \frac{1}{2(\beta'/\gamma)^3} - \frac{3}{4}\,\frac{1}{(\beta'/\gamma)^4} + \frac{3}{4}\,\frac{1}{(\beta'/\gamma)^5}\right\}\right] =$$

$$= 30\ [\ 1 + 0.4\,(x+y)\ ]\quad \text{Mev - mb,}$$

which becomes 37.6, 39.6 and 41.2 Mev-mb for Serber, Rosenfeld and Inglis mixtures of forces respectively. These three values are all in fair agreement with the experimental value[15] of 38 Mev-mb, for E-1 transitions integrated to 155 Mev. Since σ_{int} depends on interactions in the final state, we see that the high energy cross section is affected appreciably by these interactions.

We would also like to remark that the serious disagreement between calculations and experiment in Fig. 1 for photon energies greater than 30 ϵ, shows that other effects not considered here (e.g., interaction in the final state and/or mesonic effects[16]) are of more importance than the inclusion of this small repulsive core in a central potential of Serber character.

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