DEVIATIONS

OF

TENSOR FORCE STRENGTH

FROM

OPEP VALUES

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by

ROHITASHVA

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AUTHOR: Rohitashva

SUPERVISOR: Dr. Donald W. L. Sprung

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SCOPE AND CONTENTS:

This thesis presents a study of experimental evidence for the depth of the tensor force in the region 1.5 to 3.0 fms., assuming the One-Pion-Exchange Potential (OPEP) beyond. The interest in this question is related to the fitting of a velocity dependent potential, for radii $<$ 1.5 fm., for use in many-body calculations. The method employed is to examine effect on the observables of tensor force splitting in the phase-shifts for proton-proton scattering. It was found that the data favour a tensor force very close to the OPEP in the region studied.

PREFACE

The remarkable binding between the neutrons and protons, in spite of the well known coulomb repulsion among the electrically positive protons, is not very well understood. However, now a considerable progress is on record and the inter-nucleon forces are being understood more and more.

Obviously the inter-nucleon forces have to be stronger than the coulomb forces. Their range has to be considerably shorter than the atomic dimensions to preserve the definition of the nucleus. This follows the α-scattering experiments of Rutherford in 1911. The nuclear force range is believed to be about 2 fms. Further, a knowledge of the per nucleon binding energy reveals the saturation of nuclear forces. Also, there are evidences for the charge independence of the nuclear forces meaning that the purely nuclear forces between any two nucleons in the same spin and angular momentum states are equally strong.

More information about the inter-nucleon forces comes from the study of the two body interactions[25], both in the negative and positive energy states. But, since the nature of these forces is not definitely known at least for distances less than 1.5 fms., phenomenological potentials are constructed to fit the experimental data. These potentials involve an infinitely repulsive core of radius 0.4 to 0.5 fm., a central force, and a tensor force. A short range ($\approx$ 0.8 fms.) but strong spin-orbit force is also included at higher energies in linear as well as quadratic forms. All potentials are of different strength in the different spin and i-spin states. The strength, of course, is a function of distance and even changes sign in some cases; e.g. the triplet central odd parity potential is weakly repulsive outside about 1.5 fm., strongly repulsive inside the hard core, and attractive in-between. Some of the realistic potentials are those given by Feshbach and Lomon[26], Hamada and Johnston[27], Breit[28], and by Gammel and Thaler[13].

As an alternative to the hard core potential the boundary condition model[14] is suggested, in which a boundary value consistent with the experimental data is imposed on the logarithimic derivative of the wave-function at the hard core. But both of these potentials present considerable difficulties in the perturbation theory used in calculation of the properties of complex nuclei, because the hard core means a sort of discontinuity while in the other case the potential is not known in the region of hard core. To get over this difficulty attempts have been made to construct the velocity dependent[29] potentials.

In application to nuclear matter, the convergence of perturbation theory is very dependent upon the ratio of central to tensor forces in the potential. In the two body problem this ratio is not well determined either by the deuteron or by low energy data. The tensor forces first contribute in the second order perturbation theory; if tensor forces are strong the second order terms are quite comparable with the first order ones. Since it is generally accepted that the interaction V is asymptotically equal to OPEP the potential models include a strong tensor force, particularly if they agree with OPEP at r as short as 1.5 fm. In fact, V(Tensor) $\sim (1+3/x + 3/x^2)\, e^{-x}/x$, and V(Central) $\sim e^{-x}/x$; x being distance parameter. If the tensor interaction were substantially weaker than the OPEP out to 3 fms., a potential with an over all weaker tensor force would result. It has, therefore, been interesting to investigate the evidence for V(Tensor) = V(OPEP — Tensor) in the range r = 1.5 to 3 fms.

Although the deuteron state is more interesting from some points of view, this work is restricted to the triplet odd (T=1) states, since the P-P data are more accurate. These states have a high statistical weight in nuclear matter. For scattering at 300 MeV ($k \approx 1.9$ fms.) the ℓ^{th} partial wave is mainly scattered at radii $\simeq \sqrt{\ell(\ell+1)}/k$. For the range under consideration, this means L = 5 partial waves. In accurate phase shift analysis(17),(18) of the scattering data, the L = 5 waves are, in fact, given OPEP phases. The effect of weakening the tensor force on the J = 6 coupling parameter is also considered.

I gratefully acknowledge the guidance and encouragements I have always received from Dr. Donald W. L. Sprung. For financial support I am very much indebted to the Physics Department of McMaster University and to the Government of Ontario. I wish to thank Miss Maureen Murphy for typing this thesis.

CONTENTS

CHAPTER I

PROTON-PROTON SCATTERING

Density Matrix for P-P Ensemble:

The spin state of a proton can be completely described by a spinor of two components each being proportional to the probability of the proton being in one spin state. The spin state, at any instant, of a beam of protons can be described by considering a statistical mixture of the two substates, $|\Psi_1\rangle$ and $|\Psi_2\rangle$, which make a complete set of orthonormal functions in the two dimensional proton spin space. If the respective weights of the substates be W_1 and W_2 such that each of the W's is ≥ 0, and

$$W_1 + W_2 = 1,$$

the expectation value of the spin operator, $\underline{\sigma}$, (or any operator in general) along the axis of quantization is given by:

$$\begin{aligned}\langle\underline{\sigma}\rangle_{beam} &= \text{Polarisation, } \underline{P} \\ &= \sum W_n \langle\Psi_n|\,\underline{\sigma}\,|\Psi_n\rangle \,/\, \langle\Psi_n|\Psi_n\rangle \\ &= \mathrm{Tr}\sum (W_n . R_{(\Psi_n)}) . \,\underline{\sigma}\,/\langle\Psi_n|\Psi_n\rangle \\ &= \mathrm{Tr}(\rho\sigma)/\mathrm{Tr}(\rho), \qquad (1)\end{aligned}$$

where

$$\rho = \sum_{n=1}^{2} W_n . R(\Psi_n), \qquad (2)$$

and $R_{(\Psi_n)}$ is a projection operator in the spin space with properties:

$$R_{(\Psi_n)} = \Psi_n . \delta_{nm} .$$

With the chosen normalisation it is obvious from (2) that

$$Tr(\rho) = W_1 + W_2 = 1 = \text{Beam Intensity.} \qquad (3)$$

Therefore, equation (1) becomes

$$\langle \underline{\sigma} \rangle_{beam} = Tr(\rho \underline{\sigma}) \qquad (1')$$

The ρ defined in equation (2) is called "Density Matrix". It is evidently a 2x2 hermitian matrix and has a pure discrete spectrum of eigen-values W_1 and W_2;

$$\rho | \Psi_n \rangle = W_n | \Psi_n \rangle$$

and, therefore,

$$\langle \Psi_n | \rho | \Psi_n \rangle = W_n \geqslant 0.$$

As a general rule physical state of a system in a space of N dimensions can be completely known in terms of the expectation values of a complete set of hermitian operators, N^2 in number. These N^2 measurements define as many relations, like (1), which can be solved to find ρ of the system. Once the density matrix is known expectation value of any operator follows from the equation (1). The density matrix of a system can, therefore, be taken to contain a complete information of the system.

In the spin space of protons ρ can be expanded in terms of a complete set of 2x2 linearly independent and hermitian matrices Ω^{μ}. A convenient choice is the unit matrix $\underline{1}$, and the three components of the Pauli matrices σ. Ω^{μ}'s are normalised so that

$$\mathrm{Tr}(\Omega^{\mu}\,\Omega^{\nu}) = 2\delta_{\mu\nu}. \qquad (4)$$

Therefore, using (1)

$$\langle\Omega^{\mu}\rangle_{beam} = \mathrm{Tr}(\rho\,\Omega^{\mu})$$

i.e.

$$\rho = \tfrac{1}{2}\sum_{\mu=1}^{2}\langle\Omega^{\mu}\rangle_{beam}\,\Omega^{\mu}. \qquad (2')$$

In proton-proton scatterings any arbitrary spin state is a linear combination of $2^2 = 4$ basic states of the composite system of beam and target protons. The density matrix describing the spin properties of a p-p scattering is, therefore, a 4x4 matrix in the combined spin space of the two protons. Equations (1'), (4) and (2') now read, before collision, as:

$$\langle\underline{\sigma}\rangle = \mathrm{Tr}(\rho\,\underline{\sigma}) \qquad (5)$$

$$\mathrm{Tr}(\Omega^{\mu}\Omega^{\nu}) = \frac{1}{4}\,\delta_{\mu\nu} \qquad (6)$$

$$\rho = \frac{1}{4}\sum_{\mu=1}^{4}\langle\Omega^{\mu}\rangle\,\Omega^{\mu}. \qquad (7)$$

where Ω^{μ}'s constitute a complete set of $4^2 = 16$ mutually orthogonal, independent, and hermitian matrices, and ρ, now, describes the p-p system completely, before collision.

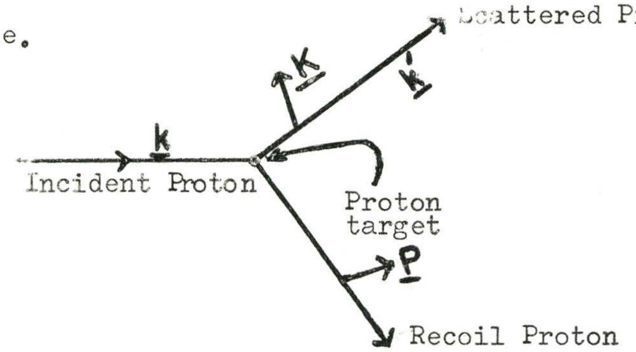
If the 16 Ω^{μ}'s are obtained as a simple product of the matrices $\underline{1}, \underline{\sigma}^1$ for the beam protons and $\underline{1}, \underline{\sigma}^2$ for the target protons, the equation (7) becomes:

$$\rho = 1 + \langle\underline{\sigma}^1\rangle.\,\underline{\sigma}^1 + \langle\underline{\sigma}^2\rangle.\,\underline{\sigma}^2 + \sum_{ij}^{3}\langle\sigma_i^1.\,\sigma_j^2\rangle.\,\sigma_i^1\,\sigma_j^2$$

or,

$$\rho = 1 + \underline{P}^1 . \underline{\sigma}^1 + \underline{P}^2 . \underline{\sigma}^2 + \sum_{i,j}^{3} C_{ij}\, \sigma_i^1 \; \sigma_j^2, \qquad (8)$$

where the definition of polarisation $\underline{P}$ is used and the coefficients C_{ij} are defined. σ_i's are the components of $\underline{\sigma}$ along a suitable set of three orthogonal directions $\underline{N}$, $\underline{K}$, and $\underline{P}$. The usual choice is: $\underline{N} = \underline{k} \times \underline{k}'/\sin\theta$, $\underline{K} = (\underline{k}'-\underline{k})/2\sin\frac{\theta}{2}$, and $\underline{P} = (\underline{k}+\underline{k}')/2\cos\frac{\theta}{2}$; where $\underline{k}$ and $\underline{k}'$ are the unit vectors in the directions of incident and scattered protons in lab system and θ is the center of mass scattering angle.



N is orthogonal to the plane of scattering.

The C_{ij}'s are the spin correlation coefficients measuring the average expectation value of the spin of the proton 1 being in the $\underline{i}$ direction in correlation with the average expectation value of the spin of the proton 2 in the $\underline{j}$ direction. However, before collision it is rather hard to conceive of the C_{ij}'s.

Scattering Matrix:

A two proton ensemble can be found in either of the four possible spin states. It can be described by 4 dimensional spinors, say χ and χ', before and after collision, respectively. A general χ can be written as:

$$\chi = \sum_{i=1}^{4} a_i \, \phi_i,$$

where a_i is the amplitude of the i'th spin state in the incident plane wave, and

$$\phi_1 = \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix}, \quad \phi_2 = \begin{pmatrix} 0 \\ 1 \\ 0 \\ 0 \end{pmatrix} \text{ etc.}$$

The spin state before and after the scattering need not necessarily be the same. One can work out a scattering matrix M in the combined spin space of the two protons that will affect every initial spin state (described by ρ) and will contain complete information of the p-p scattering. Wolfenstein[(1), (2)] has defined the M as follows:

$$f_i(\theta,\phi) = \sum_{j=1}^{4} M_{ij}(\theta,\phi)\, a_j,$$

where $f_i(\theta,\phi)$ is the amplitude for scattering in the spin state ϕ_i at an angle θ,ϕ. Elements M_{ij} of M depend on the momentum vectors $\underline{k}, \underline{k}'$ and on the spins of the two protons. The basis states ϕ_i can be taken to be either singlet-triplet states or the spin-spin states.

While talking of the phase shifts it is convenient to use the singlet triplet representation in which the elements of χ represent amplitudes and relative phases of the singlet state (S=0) and the three triplet states for S=1, $m_s = \pm 1, 0$ of the two proton system. The M is of the form

$$M(\underline{k},\underline{k}', \underline{\sigma}^1, \underline{\sigma}^2) = \begin{array}{c|cccc} m_s \backslash m_s' & s & 1 & 0 & -1 \\ \hline s & M_{ss} & 0 & 0 & 0 \\ 1 & 0 & M_{11} & M_{10} & M_{1-1} \\ 0 & 0 & M_{01} & M_{00} & M_{0-1} \\ -1 & 0 & M_{-11} & M_{-10} & M_{-1-1} \end{array} \qquad (9)$$

where M_{ss} is the singlet scattering amplitude, and

$$M_{ij} = \langle \chi_{s=1,m_s=i} | M | \chi_{s=1,m_s=j} \rangle \quad i,j=\pm 1,0 . \qquad (10)$$

The zero elements in M signify that there is no connection between the singlet and triplet states. This follows from the parity conservation and the charge independence* of nuclear forces.

Conservation of the angular momentum and parity demand the invariance of M under rotation and inversion of the space co-ordinate axes, respectively. Also, so far as the pure elastic scattering is concerned, behaviour of M should remain unchanged under a time reflection.

It is particularly useful to think of M in the spin-spin representation while dealing with observables. Wolfenstein and Ashkin(2) have given a most general form of the M as follows:

$$M(\underline{k},\underline{k}') = a+ic(\underline{\sigma}_1 + \underline{\sigma}_2).\underline{N} + m(\underline{\sigma}_1.\underline{N}\,\underline{\sigma}_2.\underline{N}) + (g+h)(\underline{\sigma}_1.\underline{P}\,\underline{\sigma}_2.\underline{P}) + (g-h)(\underline{\sigma}_1.\underline{K}\,\underline{\sigma}_2.\underline{K}), \qquad (11)$$

where the notation used is that of Phillips(3), which differs from the Wolfenstein's(2) in having ic in place of c**.

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*

In fact the charge independence makes sense only in the neutron-proton scattering where the states with T=1 as well as T=0 are allowed.

**

The term $D(\underline{\sigma}_1 - \underline{\sigma}_2).\underline{N}$ appearing in the reference (2) has been left out to prevent a mixing of the singlet and triplet states.

$\underline{N}$ and $\boldsymbol{\sigma}$ are axial vectors while $\underline{K}$ and $\underline{P}$ are polar vectors. Polar vectors change sign under a space inversion, while only $\underline{K}$ remains invariant under a time reflection. Therefore, to keep (11) invariant under space rotations, space inversions, and time reflections, the coefficients a, c, m, g, and h have to be invariant under these transformations. These coefficients are functions of the scalars k^2 (energy) and $\underline{k}.\underline{k}'$ (c.m. scattering angle, θ).

M of (11) is again a 4x4 matrix operating on the 4 dimensional spinor χ. The elements of χ, in the spin-spin representation, are the states with spins for the two protons $\uparrow\uparrow$, $\uparrow\downarrow$, $\downarrow\uparrow$ and $\downarrow\downarrow$. These are the states 1,1 ($s = 1$, $m_s = 1$), $(1, 0 + ss)/\sqrt{2}$, $(1,0 - ss)/\sqrt{2}$ ($1, 0 \equiv s = 1$, $m_s = 0$, while ss represents the singlet state $s = 0$, $m_s = 0$), and 1, - 1 ($s = 1$, $m_s = - 1$), respectively. One can go from spin-spin to singlet triplet representation by means of an unitary operator.

$$\begin{pmatrix} ss \\ 1,1 \\ 1,0 \\ 1,-1 \end{pmatrix} = \begin{pmatrix} 0 & 1/\sqrt{2} & -1/\sqrt{2} & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 1/\sqrt{2} & 1/\sqrt{2} & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1,1 \\ \frac{1,0+ss}{\sqrt{2}} \\ \frac{1,0-ss}{\sqrt{2}} \\ 1,-1 \end{pmatrix}$$

$$\chi_{(\text{singlet-triplet})} \qquad U \qquad \chi_{(\text{spin-spin})}.$$

It is obvious that U is a unitary operator, since it satisfies

$$U^{+}U = UU^{+} = 1$$

Also, one can write (11) as a matrix

$$= U^{+} M_{(eq.10)} U$$

$$= \begin{array}{c} \\ \\ \\ \\ \\ \end{array}\begin{array}{cccc} \uparrow\uparrow & \uparrow\downarrow & \downarrow\uparrow & \downarrow\downarrow \end{array}$$

$$= \left(\begin{array}{cccc} M_{11} & M_{10}/\sqrt{2} & M_{10}/\sqrt{2} & M_{1-1} \\ M_{01}/\sqrt{2} & \frac{M_{00}+M_{ss}}{2} & \frac{M_{00}-M_{ss}}{2} & M_{0-1}/\sqrt{2} \\ M_{01}/\sqrt{2} & \frac{M_{00}-M_{ss}}{2} & \frac{M_{00}+M_{ss}}{2} & M_{0-1}/\sqrt{2} \\ M_{-11} & M_{-10}/\sqrt{2} & M_{-10}/\sqrt{2} & M_{-1-1} \end{array} \right) \begin{array}{c} \uparrow\uparrow \\ \uparrow\downarrow \\ \downarrow\uparrow \\ \downarrow\downarrow \end{array}$$

Putting M of (11), with $\underline{k}$ in the positive z direction, in (10) it follows (e.g. $M_{11} = a + g + h\cos\theta$ in Appendix A) that:

$$M = \begin{array}{c|cccc} m_s \backslash m_{s'} & s & 1 & 0 & -1 \\ \hline s & a-m-2g & 0 & 0 & 0 \\ 1 & 0 & a+g+h\cos\theta & \sqrt{2}e^{-i\phi}(c+h\cos\theta) & e^{-2i\phi}(g-m-h\cos\theta) \\ 0 & 0 & \sqrt{2}e^{i\phi}(h\sin\theta-c) & a+m-2h\cos\theta & \sqrt{2}e^{-i\phi}(c-h\sin\theta) \\ -1 & 0 & e^{2i\phi}(g-m-h\cos\theta), & -\sqrt{2}e^{i\phi}(c+h\sin\theta), & a+g+h\cos\theta \end{array} \quad (12)$$

The following symmetries among the elements of M are obvious:

$$M_{11} = M_{-1-1}$$
$$M_{1-1}(\theta,\phi) = M_{-11}(\theta,-\phi)$$
$$M_{10}(\theta,\phi) = -M_{-10}(\theta,-\phi) \qquad (13)$$
$$M_{01}(\theta,\phi) = -M_{0-1}(\theta,-\phi),$$

and the useful check relation

$$M_{11}-M_{00}-e^{2i\phi}M_{1-1} = \sqrt{2}\cot\theta\,(e^{i\phi}M_{10}+e^{-i\phi}M_{01}) \qquad (14)$$

Equations (13) are a consequence of parity conservation(2), and (14) follows after the condition of invariance of M under the time reversal(2).

From equations (12) the M_{ij} can be read in terms of a, c, m, g and h. By solving these relations it follows that:

$$a = \frac{1}{4}(2\,M_{11} + M_{00} + M_{ss})$$
$$c = \frac{1}{\sqrt{8}}(e^{i\phi}M_{10} - e^{-i\phi}M_{01}) \qquad (15)$$
$$m = \frac{1}{4}(M_{00} - M_{ss} - 2e^{2i\phi}M_{1-1})$$
$$g = \frac{1}{4}(M_{11} - M_{ss} + e^{2i\phi}\,M_{1-1})$$
$$h = \frac{1}{4\cos\theta}\,(M_{11} - M_{00} - e^{2i\phi}\,M_{1-1}) = \frac{1}{\sqrt{8}\sin\theta}\,(M_{10}+M_{01}).$$

The Pauli principle demands that under a space inversion, i.e. when $\theta \longrightarrow \pi-\theta$ and $\phi \longrightarrow \pi+\phi$, $M_{ss} \longrightarrow M_{ss}$ and all the other (triplet) $M_{ij} \longrightarrow -M_{ij}$. These restrictions when applied to equations (15) give the following relations between the coefficients a, c, m, g, and h at the center of mass angle θ to those at $\pi-\theta$.

$$c(\pi-\theta) = c(\theta)$$
$$h(\pi-\theta) = h(\theta)$$
$$a(\pi-\theta) = A(\theta)-g(\theta) \qquad (16)$$
$$m(\pi-\theta) = A(\theta)+g(\theta)$$
$$g(\pi-\theta) = (m(\theta)-a(\theta))/2,$$

where

$$A(\theta) = -(a(\theta)+m(\theta))/2$$

M_{ij}'s in terms of Phase-shifts:

The Schrödinger equation describing the combined coulomb and nuclear scattering is:

$$\left(-\frac{h^2}{M}\nabla^2 + V + \frac{e^2}{r}\right)\Psi = \tfrac{1}{2} E \Psi, \qquad (17)$$

where M is a proton mass, e the elementary charge, E the laboratory energy of the incident proton, and V the nuclear potential discussion of which is reserved for the next chapter. The solution of (17), Ψ, is 4 component spinor; its i^{th} component has the asymptotic form[4]

$$\Psi_{(i)} \sim (1-\xi_{\varsigma\sigma\tau})e^{i(\underline{k}\cdot\underline{r}+\eta\ln(kr-\underline{k}\cdot\underline{r}))}\chi_{(i)} + \frac{e^{i(kr-\eta\ln 2kr)}}{r}\sum_{j} M_{ij}\chi_{(j)}, \qquad (18)$$

where $\xi_{\beta\sigma\tau}$ is the particle exchange operator in the combined space, $\chi_{(i)}$ is the i^{th} component of the spinor χ describing the p-p system before collision,

$$k = \frac{ME/2}{\hbar^2},$$

and

$$\eta = \frac{e^2}{\hbar v};$$

v being the lab velocity of the incident proton. Choosing our basis in spin space as the singlet-triplet states the M_{ij}'s are those occuring in equations (12), (15). Stapp[5] has written these M_{ij}'s explictly in terms of the phase-shifts and the coupling parameters as:

$$M_{ss} = f_c(\theta)+f_c(\pi-\theta)+ \sum_{\text{even } L} (2L+1) \alpha_L P_L(\theta)/ik$$

$$M_{11} = f_c(\theta)-f_c(\pi-\theta)+ \sum_{\text{odd } L}\Big((L+2)\alpha_L^{L+1} + (2L+1)\alpha_L^{L}$$

$$+(L-1)\alpha_L^{L-1} - U\Big) P_L(x)/2ik$$

$$M_{00} = f_c(\theta)-f_c(\pi-\theta)+ \sum_{\text{odd } L}\Big((L+1)\alpha_L^{L+1} + L\,\alpha_L^{L-1} + U\Big) P_L(x)/ik$$

$$M_{01} = \sum_{\text{odd } L}\Big(\frac{L-1}{L}\alpha_L^{L-1} + \frac{2L+1}{L(L+1)}\alpha_L^{L} - \frac{L+2}{L+1}\alpha_L^{L+1} + V\Big)\frac{\partial P_L(x)}{\partial x}\sin\theta/\sqrt{2}ik$$

$$M_{10} = \sum_{\text{odd } L}\Big(\alpha_L^{L+1} - \alpha_L^{L-1} + V\Big)\frac{\partial P_L(x)}{\partial x}\sin\theta/\sqrt{2}ik$$

$$M_{1-1} = \sum_{\text{odd } L}\Big(\alpha_L^{L+1}/(L+1) - \frac{2L+1}{L(L+1)}\alpha_L^{L} + \alpha_L^{L-1}/L - \alpha^{L-1}/\sqrt{L(L-1)}$$

$$- \alpha^{L+1}/\sqrt{(L+1)(L+2)}\Big)\frac{\partial^2 P_L(x)}{\partial x^2}\sin^2\theta/2ik, \qquad (19)$$

where

$$U = \sqrt{(L+1)(L+2)}\,\alpha^{L+1} + \sqrt{L(L-1)}\,\alpha^{L-1} \text{ and } V = \sqrt{\frac{L+2}{L+1}}\,\alpha^{L+1} - \sqrt{\frac{L-1}{L}}\,\alpha^{L-1},$$

and the remaining non-zero M_{ij}'s are the same as one's in (19) within a sign as is obvious from equations (13), when the azimuthal dependence is not important. $P_L(x)$'s are the Legendre polynomials of the first kind, of the order L -- the angular momentum of the partial wave in question. $x = \cos\theta$ when θ is the center of mass scattering angle. The α's in (19) are functions of the phase-shifts:

$$\alpha_L = e^{2i(\delta_L+\phi_L)} - e^{2i\phi_L}$$

$$\alpha_L^J = \sqrt{1-\rho_J^2}\; e^{2i(\delta_L^J+\phi_L)} - e^{2i\phi_L}$$

$$\alpha^J = i\,\rho_J\; e^{i(\delta_{J+1}^J+\delta_{J-1}^J)},$$

where δ's are the Nuclear Bar[5] phase shifts (δ_L refers to the singlet states and δ_L^J to the triplet states for $J = L \pm 1$, L), ρ_J's are the coupling constants* coupling states with $J = L \pm 1$ ($\rho_{J=L} = 0$), and ϕ_L's are the coulomb phase-shifts given by

$$\phi_L = \sum_{Y=1}^{L} \text{Arctan}\,\frac{\eta}{Y}.$$

The f_c appearing in (19) is the coulomb scattering amplitude:

$$f_c(\theta) = -\frac{\eta/k}{1-\cos\theta}\; e^{-2i\eta \ln \sin\frac{\theta}{2}}.$$

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* $\rho_J = \sin 2\bar{\epsilon}_J$, and in reference (5) $\bar{\epsilon}_J$ is called the coupling constant.

Observables:

The density matrix ρ, of equation (7), describes the proton-proton system before collision. During collision

$$\rho \longrightarrow \rho_f = M \rho M^* . \qquad (20)$$

ρ_f, the density matrix after collision, contains every information about the two protons after scattering. ρ_f is now known if one knows M, i.e. the five complex coefficients a, c, m, g, h. To know them completely (within an overall phase) at a given energy and scattering angle one has to have the measurements of at least nine independent observables. However, to get rid of the possible algebraic degeneracy in the values of the coefficients additional measurements independent of the original nine are needed.

Observables are related to the coefficients a, c, m, g, h through the equations of the form (1) with ρ given by (8). The simplest of all is the measurement of differential scattering cross-section, $I(\theta,\phi)$, which by definition is given by

$$I_{(\theta,\phi)} = T_r \, (\rho_f) = T_r \, (M \rho M^*), \qquad (21)$$

for an incident beam of unit intensity ($Tr \, \rho = 1$, equation 3). The other possible types of measurements are of the polarisations of either protons, and of the coefficients C_{ij} defined in equation (8). Each of these three types of measurements (of I, $\underline{P}^{1,2}$, C_{ij}) can be done in three different cases when, (i) $\underline{P}^{1,2} = 0$ (therefore $C_{ij} = 0$), (ii) one of the $\underline{P}^{1,2}$'s is non zero (but $C_{ij}=0$), and (iii) both $\underline{P}^{1,2} \neq 0$. Thus, nine different kinds of scattering experiments are possible to help investigation of the M.

The measurement of any observable, say Y, in general, after scattering is (given by equation 1) equal to

$$\langle Y\rangle_f = \frac{Tr(\rho_f Y)}{Tr\ \rho_f} = Tr\ (M\rho M^*Y)/I, \qquad (22)$$

where use has been made of the equation (21). If ρ, from equation (8), is inserted into the (22) it is seen that $I\langle Y\rangle_f$ consists in the characteristic terms of the forms

$$Tr\ (M\ X\ M^*\ Y),$$

where X is any one of the spin dependent terms in ρ. Phillips, in reference (3), has listed and discussed characteristic terms which are different in the nine kinds of experiments. All observables can be expressed as linear combinations of these characteristic terms. Phillips has also written[(3)] explicit expressions for all the possible measurements* in terms of the coefficients a, c, m, g, h. However, all of them are not different. These measurements involve double and triple scattering experiments, and the analysis in coincidence. In some of them a magnetic field is used to allow the measurement of the longitudinal component of spin in the scattered and recoil beams. Kanellopoulos and Brown[(6)] have pointed out that these experiments give, in all, eleven (different) pieces of information without a magnetic field, and twenty-three with a magnetic field.

It is interesting to look at the spin correlation coefficients in a little detail. With Y as $\underline{\sigma}_1 \cdot \underline{\sigma}_2$ in equation (2) Wolfenstein[(7)] has written a general expression,

$$I\langle \sigma_1 \sigma_2\rangle = I_0\Big((C_{NN}+C^P_{NN}\ \underline{P}^1_i.\underline{N})\underline{N}.\underline{N} + (C_{KP}+C^P_{KP}\ \underline{P}^1_i.\underline{N})\underline{K}.\underline{P} + (C^P_{KN}\ \underline{P}^1_i.\underline{N}x\underline{k}')\underline{K}.\underline{N}+(C^P_{NP}\ \underline{P}^1_i.\underline{N}x\underline{k}')\underline{N}.\underline{P}\Big), \qquad (23)$$

---
* some of these will be called in the Chapter III.

where $\underline{P}^1$'s are subscripted i to refer to the incident beam, and the C^P_{ij} are correlation coefficients when the incoming beam is polarised. I_0 in (23) is the cross-section corresponding to unpolarised incident beam. It is assumed that only the component of polarisation perpendicular to the direction of flight is measured. The measurements of coefficients C_{PP} and C_{KK} involve the study of the longitudinal component of polarisation and require magnetic field normal to the direction of flight.

Of all the correlation coefficients C_{NN} is the simplest. In its measurement both of the analysing scatterings and the main scattering are coplanar. Brown and Kanellopoulos find

$$C_{N,N} = \frac{I_{11} + I_{1-1} - I_{10} - I_{ss}}{I_{11} + I_{1-1} + I_{10} + I_{ss}}, \qquad (24)$$

where I_{ss} denotes the cross-section for singlet scattering, and the rest of the I's are the three triplet scatterings. At 90° (c.m.) I_{10} vanishes[(8)] and, therefore,

$$C_{N,N}\,(90^\circ) = \frac{(I_{11}+I_{1-1})-I_{ss}}{(I_{11}+I_{1-1})+I_{ss}},$$

determines the triplet and singlet scattering cross sections at this angle, provided the sum of the two (i.e., the total cross-section) is known. Also, the value of $C_{NN}(90^\circ)$ being significantly different from −1 supports the conjecture of strong spin dependent forces, since a central force does not give any triplet scattering at 90° in the center of mass system.

No such simple comments are possible about the other correlation coefficients.

CHAPTER II

ONE PION EXCHANGE POTENTIAL

It is well established that nucleons interact through the exchange of one or more pions, neutral in the case of the proton-proton interaction. Pions are pseudoscalar particles and their coupling with a nucleon can be correctly represented only by the Dirac theory. The field equations have been solved assuming point nucleons with non-relativistic velocities and exchanging only one pion. This leads to the one Pion Exchange Potential (OPEP), between two nucleons, of the form:

$$V_{(\underline{r}_{12})} = \frac{1}{3}\left(\frac{g\mu}{2M}\right)^2 (\boldsymbol{\tau}_1 \cdot \boldsymbol{\tau}_2) \left(S^J_{12} \left(1 + \frac{3}{X} + \frac{3}{X^2}\right) + 3\,(\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2)\left(1 - \frac{4\pi r}{\mu^2}\,\delta(r)\right) \right) \frac{e^{-X}}{r}, \qquad (1)$$

where g^2 (≈ 14) is the pion-nucleon coupling constant, M the nucleon mass and $\boldsymbol{\tau}$ their isotopic spin, $\mu = mc/\hbar$ (m being the pion mass), $X = \mu r$ (r being the internucleon distance, $|\underline{r}_{12}|$), and S_{12} is the tensor force operator given by:

$$S^J_{12} = 3\,\frac{(\boldsymbol{\sigma}_1 \cdot \underline{r})(\boldsymbol{\sigma}_2 \cdot \underline{r})}{r^2} - (\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2) \qquad (2)$$

The diagonal matrix elements of S^J_{12} for the states with $J = L-1,\ L,\ L+1$ are: $-2(L+1)/(2L-1)$, 2, and $-2L/(2L+3)$, respectively. This interaction potential, $V_{(\underline{r}_{12})}$, can be seen to obey the invariance requirements pointed out in Chapter I.

In the Yukawa's meson Theory the range of forces arising from the exchange of particles is of the order of the compton wavelength of the mass involved in exchange. This suggests that at least the long range part of the nuclear force should be expressible as OPEP, and the possibility of the exchange of two[9] or more pions is important only at short distances. Extensive studies show that OPEP is the main interaction for r>2.9f and the major one for r>1.6f[10], and its present form in the equation (1) is quite well determined[11]. It is obvious, from the elementary semi-classical considerations (for example) that, OPEP will be the only interaction affecting the higher partial waves*.

The above conclusions follow, as well, from the Dispersion theory approach in which the distance of the singularities, of the complex scattering amplitude in the cosθ plane, from the physical region ($-1 < \cos\theta < 1$) is proportional to the mass exchanged in the scattering process. All these singularities lie on the real axis, symmetrically on either side of the physical region. Their distance to the physical region decreases with energy, but maintains the same relative ratio. Therefore, the closest singularity will always be due to the exchange of one pion -- the minimum quantum of nuclear field. In actual calculations the closer singularity involves more powers of cosθ for a fair approximation, showing thereby that for the higher partial waves OPEP is the main interaction.

Modified Phase Shift Analysis:

The phase-shift analysis has been modified[12] by adding the OPEP contributions of all the higher partial waves to the

---

* For this reason the delta function term is usually not included in the usual form of the OPEP. For example, reference (11).

scattering amplitudes, which were not included in the conventional[5] phase-shift analysis. In this scheme

$$M = M_{(\delta)} + M^P - M^S, \qquad (3)$$

where $M_{(\delta)}$ is the conventional part containing contributions from only a small finite number of phenomenological phase-shifts up to a certain angular momentum, M^P is the all OPEP contribution in all the angular momentum states, and the subtracted term M^S is the OPEP contributions in the lower angular momentum states which have already been counted in $M_{(\delta)}$.

Cziffra et al.[12] have worked out the closed expressions for M^P by carrying out the Born approximation calculations in the lowest order of perturbation theory. Their results are:

$$M^P_{SS} = -g^2(\alpha + \beta)/4E$$

$$M^P_{00} = g^2(\alpha + \beta)\ x/4E = -M_{SS}\ x$$

$$M^P_{11} = M^P_{-1-1} = -g^2\Big(\alpha(1+x) - \beta(1-x)\Big)/8E$$

$$M^P_{01} = M^P_{10} = -M^P_{0-1} = -M^P_{-10} = -g^2\sqrt{2}\,(\alpha + \beta)\ \sin\theta/8E \qquad (4)$$

$$M^P_{1-1} = M^P_{-11} = -g^2\Big(\alpha(1-x) - \beta(1+x)\Big)/8E,$$

where

$$E = \sqrt{M^2 + k^2}$$

$$\alpha = (1+x)/(Y+x)$$

$$\beta = (1-x)/(Y-x),$$

and

$$Y = 1 + \frac{\mu^2}{2k^2} = \text{position of the one pion pole.}$$

The contribution corresponding to a particular angular momentum state, L, can be projected[12] out of the above expressions. The M^S's are the expressions of equations (I 19) with the new α's given[12] as:

$$\alpha_L^{L+1} = C \left(Q_{L+1} - Q_L \right) / (2L+3)$$

$$\alpha_L^{L} = C \left(LQ_{L+1} + (L+1)\, Q_{L-1} - (2L+1)\, Q_L \right) / (2L+1) \qquad (5)$$

$$\alpha_L^{L-1} = C \left(Q_L - Q_{L-1} \right) / (2L-1)$$

$$\alpha^J = (J(J+1))^{1/2} C \left(Q_{J+1} + Q_{J-1} - 2Q_J \right) / (2J+1)$$

$$\alpha_L = -C \left((Y-1) Q_L - \delta_{L0} \right) ,$$

where

$$C = -ikg^2/2E$$

and $Q_L = Q_L(Y)$ are the Legendre polynomials of the second kind and L^{th} order.

CHAPTER III

EFFECTS OF THE TENSOR FORCE

Observables of Interest:

In the Born approximation, which is quite good for describing behaviour of the rather weakly interacting higher partial waves, the contribution of tensor part of the OPEP to the α_L^J's in the M_{ij}'s can be described

$$\approx \langle L, J \mid S_{12}^J \; V_T(r) \mid L', J\rangle$$

$$= \left[S_{12}^J \right]_{LL'} \langle j_L \mid V_T(r) \mid j_{L'}\rangle, \qquad (1)$$

where $V_T(r)$ is the tensor part of the OPEP. It means that the tensor force parts of the three α_L^J's are in the ratio of the matrix elements of the S_{12}^J. Therefore, taking $\alpha_L^{J=L-1, L, L+1}$ equal to the respective matrix elements of the S_{12}^J will qualitatively pick out* the scattering matrix elements sensitive to the tensor force. It turned out that h, m, and g are the functions responding to the tensor force**in the order they are written.

---

* $\alpha^{J=L\pm1}$ may be ignored since they arise only due to the tensor force. An alternative is to use

$$\alpha^J = \sqrt{J(J+1)} \; (\alpha_{J+1}^J - \alpha_{J-1}^J),$$

which holds only when the interaction is the OPEP. It follows from the equations (II-5).

** Similar investigations indicate the following dependence of a, c, g, m, g elements on the tensor, spin-orbit, and central interactions:

The combinations of h, m, and g in the various possible[3] observables were examined for a comparison of their sensitiveness to the tensor force, and the following were selected (considering the available experimental data) for studying the tensor force part of the OPE interaction:

$$I_0 = |a^2| + |m^2| + 2\,(|c^2| + |g^2| + |h^2|)$$

$$P = -2\,\mathrm{Im}\,[c(a+m)^*]/I_0$$

$$D_{nn} = [\,|a^2| + |m^2| + 2\,(|c^2| - |g^2| - |h^2|)\,]/I_0$$

$$C_{KP} = -4\,\mathrm{Re}(ch^*)/I_0 \tag{2}$$

$$C_{NN} = 2\,[\mathrm{Re}(am^*) + |c^2| - |g^2| + |h^2|]/I_0$$

$$\$C_{KK} = 2\,\mathrm{Re}\,[(a-m)\,g^* - (a+m)\,h^*]/I_0$$

$$\$(PP:PP) = (KK:KK) = I_0 - 4\,|c^2|,$$

Tensor	Spin-orbit	Central
h, m, g	c	a, m, g

$ C_{KK} and (PP:PP) have not yet been measured. C_{KK} has been defined in Chapter I, and (PP:PP) is one of the family of[3] observables measurements of which will allow study of the effects of initial spin correlations on the final spin correlations. (PP:PP) can only be of some academic interest since its measurement is, possibly, impracticable.

where P is the amount of polarisation produced in an initially unpolarised beam. D_{nn} is a component of the depolarisation tensor, and is usually referred as "Depolarisation[7]". Hereafter it shall be called D. A measurement of D requires, probably, the simplest of the triple scattering experiments in which all scatterings are coplanar. By definition[15]

$$^{\$}D_{ij} = Tr(M \ \sigma_{1,2(i)} \ M^* \ \sigma_{1,2(j)})/I_0$$

relates the polarisation, $P_{1,2(i)}$, of the particles 1 (incident) or 2 (recoil) in the <u>i</u> direction to the polarisation, $P_{1,2(j)}$, in the <u>j</u> direction by the relation

$$P^f_{1,2(j)} = \frac{P_{(j)} + \sum_i D_{ij} P_{1,2(i)}}{1 + \underline{P} \cdot \underline{P}_{1,2}},$$

provided the ensemble of particles (1 or 2) not involved in the above equation is unpolarised at the time of scattering. $\underline{P} = P.\underline{n}$ is the polarisation, in the c.m. system, produced when an unpolarised beam is scattered at an unpolarised target.

C_{KP} and C_{KK} were also calculated using the correct relativistic expressions given by Sprung[16]:

$ In fact the combinations of the non-zero D_{ij}'s appear as the well known Wolfenstein triple scattering parameters D, A, R, R', and A' which relate[7] the final and initial polarisations. It can be seen[15] that:

$$-A = D_{KK} \sin\frac{\theta}{2} + D_{KP} \cos\frac{\theta}{2}$$

$$R = D_{KK} \cos\frac{\theta}{2} + D_{PK} \sin\frac{\theta}{2}$$

$$R' = D_{PP} \sin\frac{\theta}{2} + D_{KP} \cos\frac{\theta}{2}$$

$$A' = D_{PP} \cos\frac{\theta}{2} + D_{PK} \sin\frac{\theta}{2}$$

$$R\,C_{KP} = \text{Rel.}\ C_{KP} = C_{KP} \cos(\alpha' - \alpha) - 2\,\text{Re}\Big((a-m)g^*\Big) \sin(\alpha' + \alpha) + 2\,\text{Re}\Big((a+m)\,h^*\Big) \sin(\alpha' - \alpha)$$

$$R\,C_{KK} = \text{Rel.}\ C_{KK} = C_{KP} \sin(\alpha' - \alpha) + 2\,\text{Re}\Big((a-m)g^*\Big) \cos(\alpha' + \alpha) - 2\,\text{Re}\Big((a+m)\,h^*\Big) \cos(\alpha' - \alpha), \quad (3)$$

where

$$\alpha = (\theta/2) - \theta(\text{Lab})$$

$$\alpha' = (\phi/2) - \phi(\text{Lab}), \quad \phi = \pi - \theta. \quad \phi \text{ is the recoil angle.}$$

$$\tan\theta_L = \frac{M}{E} \tan(\theta/2)$$

$\tan\phi_L = \frac{M}{E} \cot(\theta/2)$; the subscript L refers to the Laboratory system.

Relativistic values were not found to be significantly (Appendix C) different, except at small angles in case of the C_{KP}.

Calculations:

The modified phase-shift analysis was adopted as described in Chapter II. To allow a variation, explicitly, in the tensor force part of the triplet OPEP phase shifts in the L = 5 states it was found convenient to fuse the first three of the equations (II-5) in to one to be read as:

$$\alpha^J_L = - \frac{g^2 m^2}{12Ek}\left[Q_L + S^J_{12}\left(Q_L + \frac{3k^2/\mu^2}{2L+1}\left(Q_{L-1} - Q_{L+1}\right)\right)\right]. \quad (4)$$

Summations in $M_{(\delta)}$ and M^S were terminated at L = 5 when α^6 was set equal to zero and at L = 7 when all the L = 7 phase shifts and α^8 were kept zero, and α^6 equal to its OPEP value. The strength of the tensor force in the $\alpha^J_{L=5}$'s (in the M^S) was varied from 0.2 to 1.6, at steps of 0.2, of its normal value in the OPEP (II-1) by varying the coefficient of S_{12}^{J} in (4). When the α^6 was included, it was varied too, in the M^S, by the same amount together with the variations in α_5^J's, and also independently in some cases. In some cases effects of the similar variations of only the central force part of the OPEP were also investigated.

These investigations were carried out at 345, 312, 210, and 147 Mev and the $\theta = 1^\circ, 10^\circ, 20^\circ$ ---- 80°, and 89°, with and without inclusion of the coulomb interaction. The phase-shifts and coupling parameters used in $M_{(\delta)}$ are listed on page 25. These are the YLAM(17) values except the one's marked "OPEP", where YLAM data do not exist. YLAM values of the δ_4 were taken from reference 18. The OPEP values were found out using equations (II-5) and knowing that*

$$\alpha_L^J = e^{2i\delta_L^J} - 1 \approx 2i\delta_L^J, \qquad (5)$$

where the coulomb phase-shifts and the δ_L^J's are considered very small. A comparison(19) of the OPEP phase shifts δ_5^4 and δ_5^5 with some phenomenological fits supports this approximation initially made with the assumption that OPEP is the main interaction for L = 5 partial waves.

All the calculations were done in fermi units, and the following constants were used:

---

* The so obtained formulas of the δ_L^J's are the same as derived by Breit(11) who has evaluated the Born approximation integrals of the OPEP (II-1).

Nuclear Bar Phases in radians, Breit[17]

Energy Mev / δ_L, δ_L^J, ρ_J	345	312	210	147
δ_0	-.2132	-.1482	.0716	.2232
δ_2	.1861	.1786	.1373	.1017
δ_4	.0163	.0156	.0126	.0099
δ_1^0	-.2454	-.1972	-.0373	.0654
δ_1^1	-.4984	-.4761	-.3872	-.3058
δ_1^2	.3037	.3042	.2954	.2511
ρ_2	-.0653	-.0702	-.0841	-.0933
δ_3^2	.0061	.0068	.0086	.0096
δ_3^3	-.0743	-.0708	-.0583	-.0453
δ_3^4	.0415	.0352	.0143	.0072
ρ_4	-.0581	-.0554	-.0426	-.030
OPEP: δ_5^4	.0116	.01025	.0061	.0036
OPEP: δ_5^5	-.0269	-.0243	-.0156	-.0098
OPEP: α_5^5 (Real)	.0093	.00815	.0046	.0025
OPEP: α^6	-.0214	-.0194	-.0123	-.0075
OPEP: α_5^6 (Im)	.00	.00	.00	.00
$\eta = e^2/\hbar v$	.00926	.00966	.0115	.01354

$$\hbar = c = 1$$

$$g^2 = 14$$

$$M = 4.7549\ f^{-1} \text{ (Proton mass)}$$

$$\mu = .13963 \times 5.06804\ f^{-1} = m$$

$$\pi = 3.1415927$$

$$e^2/\hbar c = 7.29732 \times 10^{-3},$$

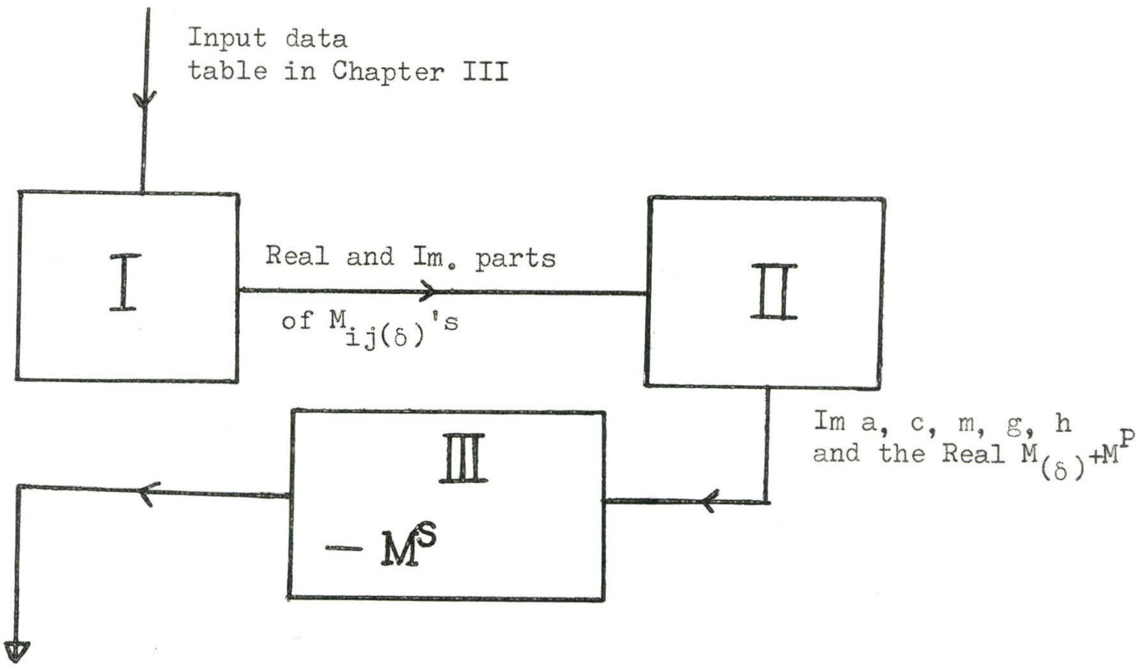
and

$$k = (1.2049\ E_{lab.})^{1/2};$$

E_{lab} is $\frac{1}{100}$ th of the laboratory energy of the Proton, in Mev.

Programming:

Complete Fortran II program is contained in the Appendix B. It was run on the McMaster's IBM 1620 of memory 40 K digits. It is in the three parts as follows:



RESULTS: observables, equations (III-2,3), with different tensor force strengths in the OPEP (II-1). These are contained in the Appendix C.

CHAPTER IV

RESULTS AND CONCLUSIONS

Some of the results are contained in the Appendix C, and shown plotted in this Chapter.

Figure 1 shows twenty six of the experimental values of the differential cross-section at 345 Mev of Chamberlain et al.[20] taken from the summary by Hess[21]. Figure 2 is the χ^2 plot for each of the curves in figure 1. χ^2 was calculated using individually* the twenty nine measured values at 345 Mev; the two omitted were those at 11.3° where the curves are not very much different.

It appears, from the figure 2, that the tensor force is pretty well fixed up in the OPEP. It can, possibly, be strengthened at the most to 1.07 of its normal strength, in the L = 5 phases and in the α^6 coupling. Although, at this stage, this conclusion holds only so far as the differential cross-section is concerned, it is obvious that no further variation is permissible. The other observables are not more sensitive to the tensor force.

---

*

The χ^2 for $S_{12} = 1.0$ is expected to be somewhat higher than the Breit's value because of the averaging[22] he has done of the results at the same angle or angles differing by 3° for $\theta > 30^\circ$, while the measurements are considerably inconsistent.

Also, their measurements are much less accurate* as compared to those of the I_0. The situation is more or less the same at the other energies studied.

A glance at the following table, which shows an estimate of the percentage differences in the values of the observables corresponding to a 20% change (for example, from 1 to 1.2) in the strength of the OPEP tensor force in δ_5^J and α^6 at 312 Mev (lab.), suggests that accurate determinations of the D and C_{KK} at some intermediate angles between 10° and 75°, and of the C_{NN} around 20° can be of help in a further fixing up of the issue. However, it calls for a tremendous improvement in the experimental skills.

Percentage differences at 312 Mev (lab.)
for $S_{12} \longrightarrow 1.2\ S_{12}$
(Coulomb interaction is not included)

θ / Observables	1°	10°	20°	30°	40°	50°	60°	70°	80°	89°
I_0	.07	.1	1.4	2.3	1.4	.35	1.2	.67	.31	.74
P	.07	.2	1.6	2.6	1.7	.24	1.4	1.2	.6	.38
D	13	4.4	.6	4.1	2.7	1.4	3.9	3.3	.5	1.9
C_{NN}	0.7	.7	11	.7	.5	.36	.06	.06	.36	.6
C_{KP}	2.1	.8	1.6	1.1	.3	.8	1.8	1.1	1.3	2.7
C_{KK}	.08	.3	.8	4	11.5	5.2	2.6	2.7	2.1	.95

---

* For example, the most recent measurements(23) of C_{KP} and C_{NN} at 400 Mev and 90° (center of mass) are good only within 15% and 28%, respectively, while the I_0 values of ref.20 at these angles have an error of only 2%.

The numbers in this table can be easily verified in case of the observables P and C_{KP} where the changes are essentially those in m_x and h_x -- the real parts of the scattering matrix elements m and h, respectively. Precisely,

$$\Delta P = 2 \, (\Delta m_x) \, Im(c),$$

and

$$\Delta C_{KP} = 4C_x(\Delta h_x)/I_0 = \sqrt{2} \; c_x \left(\Delta Re(M_{01}+M_{10}) \right)_{L=5} /I_0 \, Sin\theta$$

$$= \frac{0.8}{I_0 k} \left(\left(\lambda + \sqrt{\frac{7}{24}} \alpha^6 \right) \frac{\partial P_5}{\partial x} - \sqrt{\frac{3}{14}} \alpha^6 \frac{\partial P_7}{\partial x} \right) C_x,$$

where

$$\lambda = 3 \frac{2L+1}{(2L+3)(2L-1)} \beta ;$$

$$\beta = \frac{1}{2} \left(- \frac{g^2 \mu^2}{12Ek} \left(Q_L + \frac{3k^2/\mu^2}{2L+1} \left[Q_{L-1} - Q_{L+1} \right] \right) \right),$$

half of the coefficient of the S_{12}^J in (III-1). The half appears for the reason obvious from (III-5). Figure (3) is a plot of h_x, $c_x h_x$ and RC_{KP} for S_{12} = 1 and 1.2 at different angles.

Figures (4) and (5) show that the effects of variation of the tensor force in δ_5^J and α^6 are additive. Results in the Appendix C clearly indicate that the central part of the OPEP in L = 5 states is quite weak. This curve and the other observables are not graphed because their values for S_{12} = 1.0 and 1.2 lie very close together.

It is to be noted that the deviations of the tensor force strength are discussed only in L = 5 phases and α^6 coupling where the OPEP is reasonably well localised. The lower phases and coupling parameters have been assumed well determined. However, if the lower phase parameters were redetermined for each value of S_{12}, it may be that the χ^2 would be somewhat reduced.

Breit[24,11] has analysed the problem to see how well the ratio of central to tensor forces is determined. His findings are that the data require a ratio 1.24±.17 where 1.0 is the accepted value. This applied to the entire potential tail including the region where OPEP is not the only interaction.

Figure (6) on page 67 (Appendix C) shows the deviations of the tensor force in the phenomenological triplet odd parity potentials, from the OPEP taken to be 1. It seems that the Feshbach-Lomon[26] fit (which is the most recent one) supports our conclusion very well in region, after about 2 fms., by which the L = 5 waves are mostly influenced at the energies we have considered.

CAPTIONS

Figure 1:

345 Mev differential p-p cross-section I_o at different c.m. scattering angles θ for different strength of the OPEP tensor force in L = 5 phases and in α^6; coulomb interaction is included.

Figure 2:

χ^2 plot for the (renormalised) experimental data[20], and the calculated cross-sections at 345 Mev shown in Figure 1.

Figure 3:

Real part of the parameter h, its product with the real part of c, and the calculated (using the relativistic formula) values of the C_{KP} with the normal OPEP tensor force, and with 1.2 times the normal value at 312 Mev. Coulomb effects are not included.

Figure 4:

Comparison of the 312 Mev I_o - θ curves when the OPEP tensor force is varied separately in L = 5 phases and in α^6; coulomb interaction is ignored.

Figure 5:

312 Mev I_o - θ curves for different OPEP tensor force strengths (as marked) in both, $\delta^J_{L=5}$ phases and in α^6 coupling; the coulomb interaction is excluded.

FIGURE 1

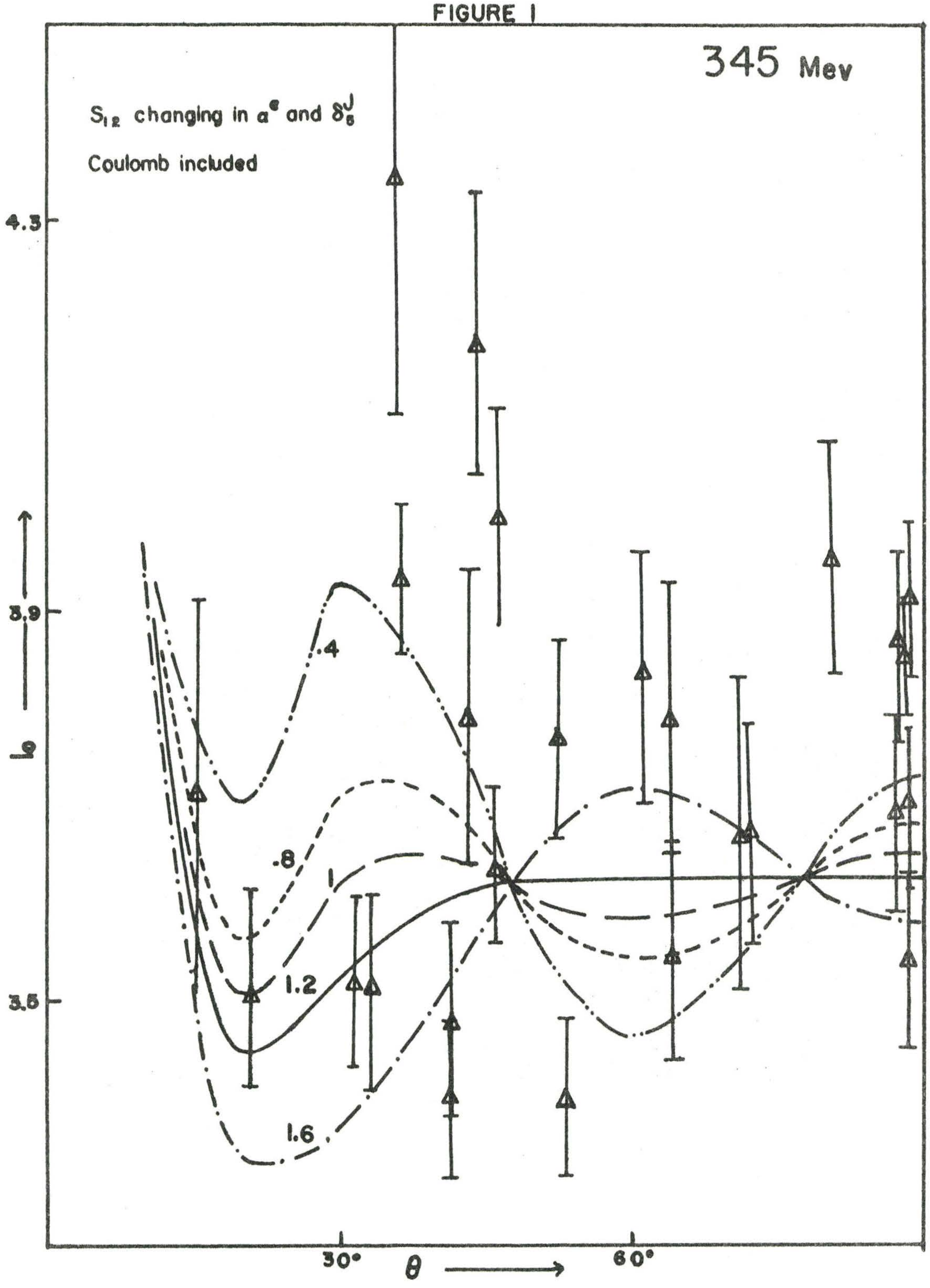

345 Mev
S_{12} changing in a^e and δ_s^J
Coulomb included
4.3
3.9
3.5
.4
.8
1
1.2
1.6
30°
60°
θ

FIG. 2

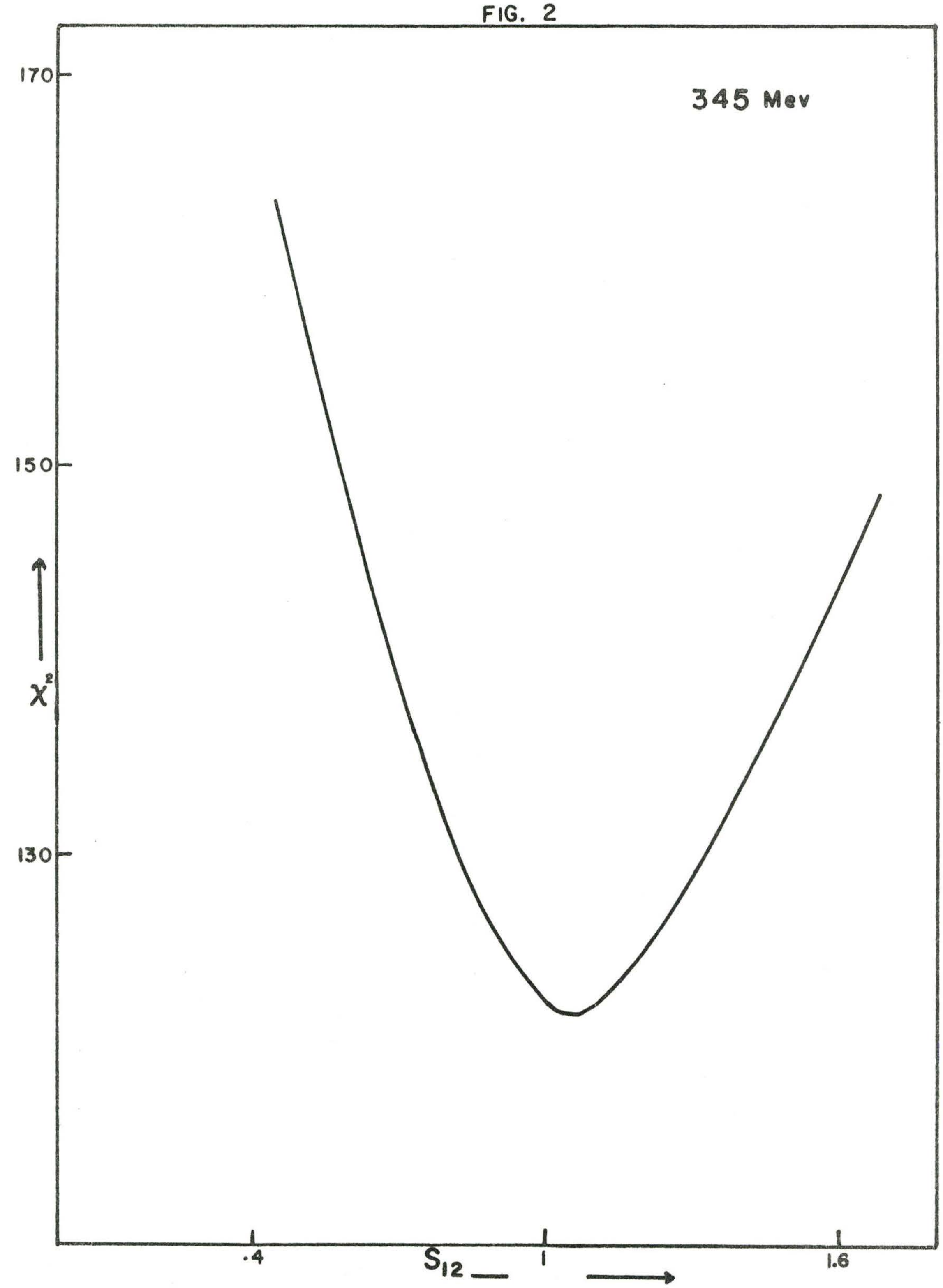


FIG. 3

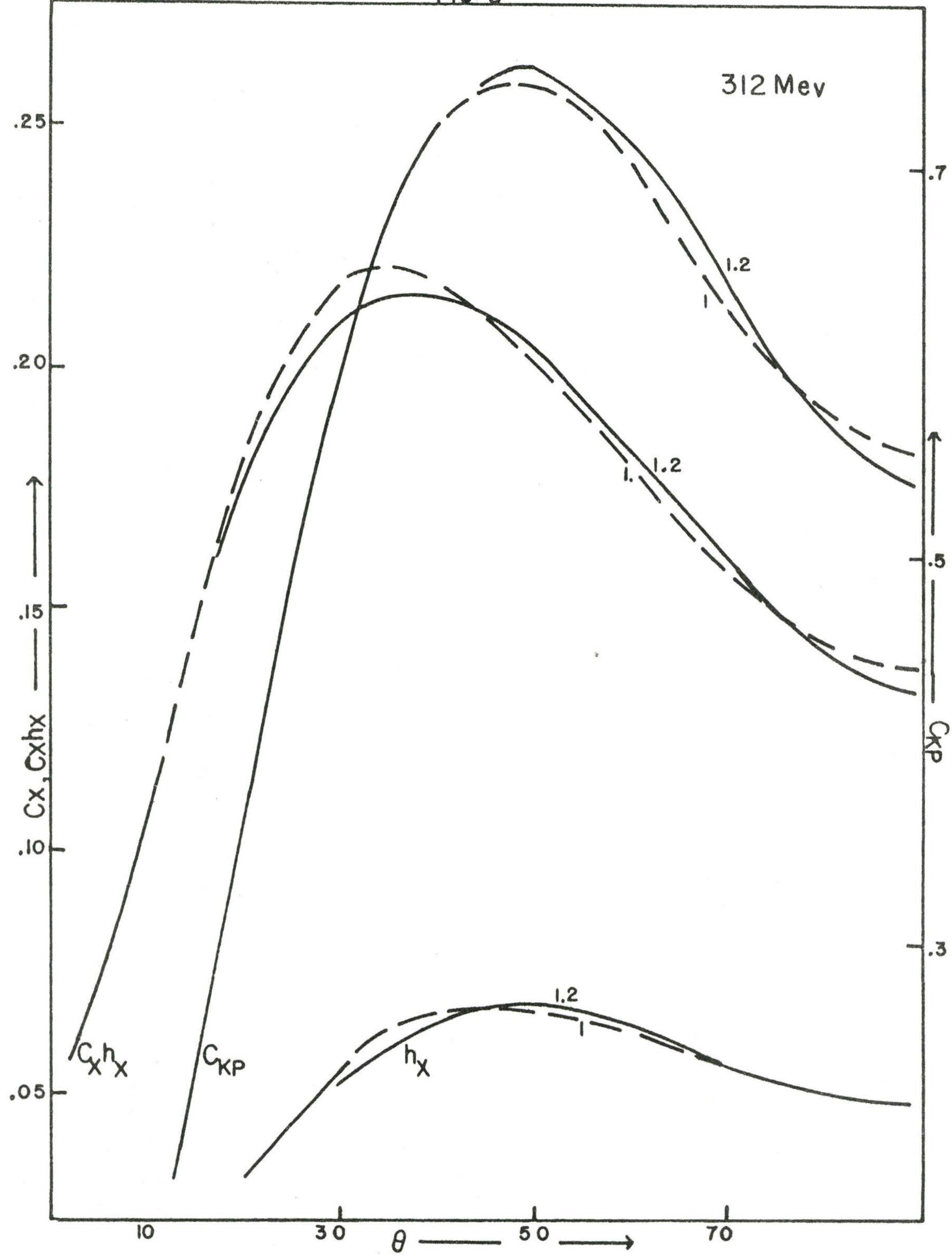
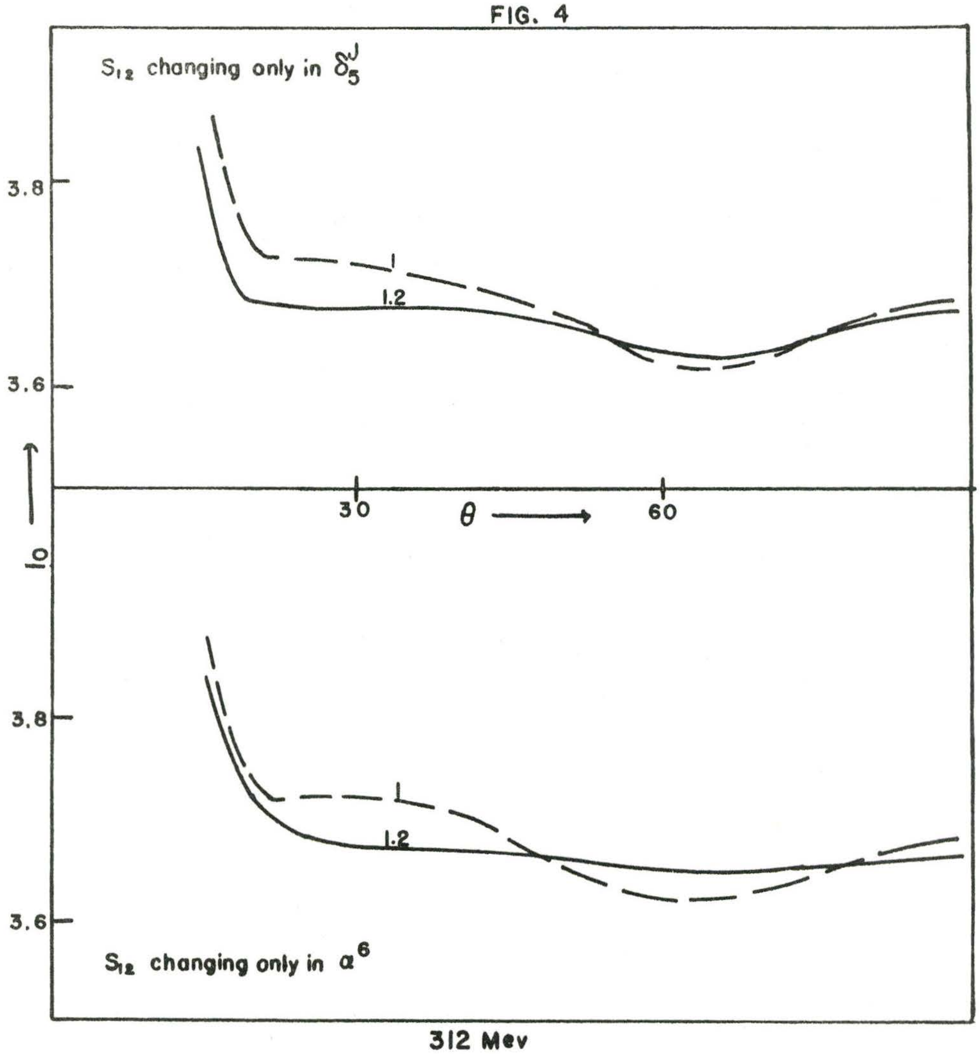
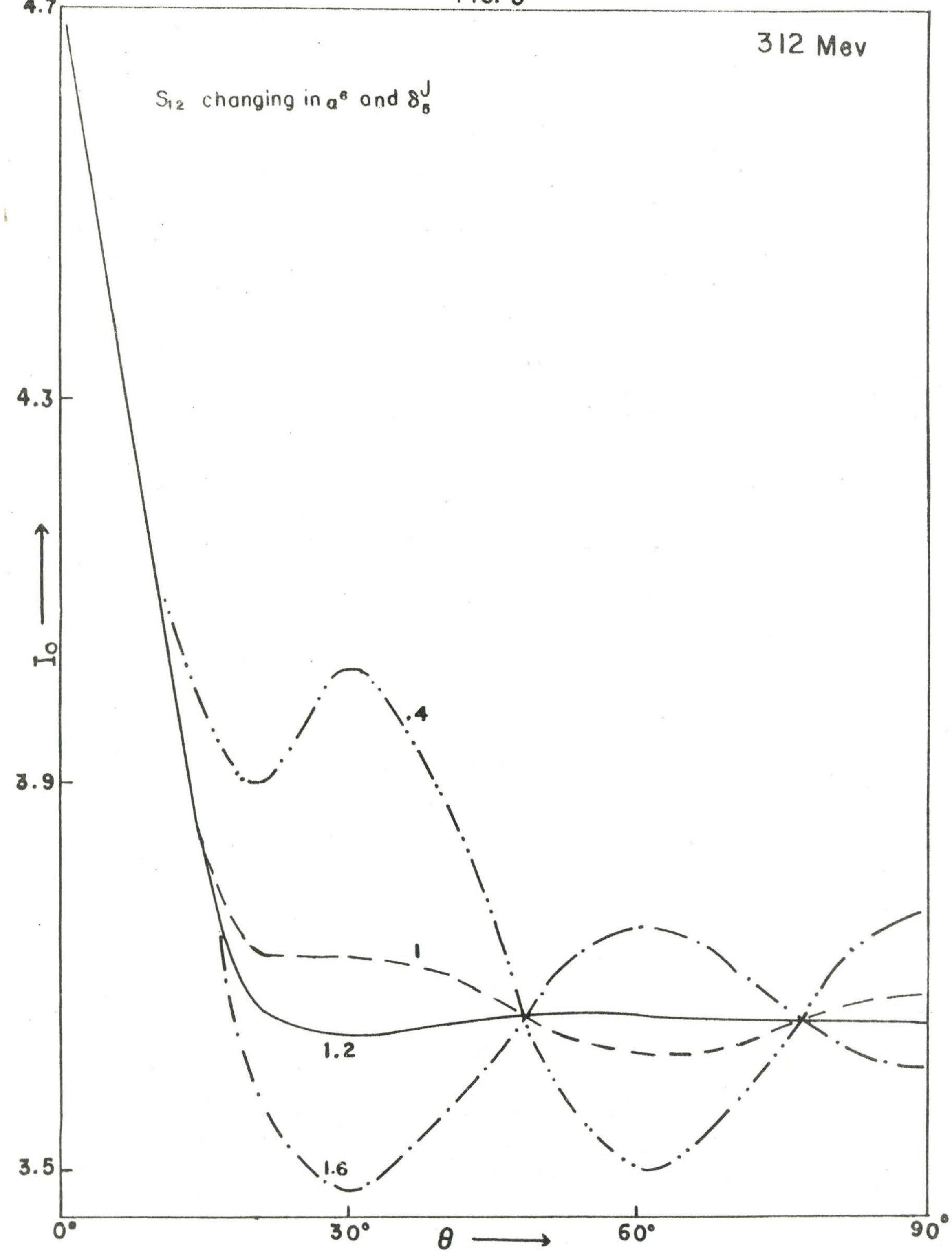

312 Mev
.25
.20
.15
.10
.05
.7
.5
.3
Cx, Cxhx
C_{KP}
$C_X h_X$
C_{KP}
h_X
1.2
1
1.
1.2
1.2
1
10
30
50
70
θ

FIG. 4


S12 changing only in δ5J
3.8
3.6
1
1.2
30
θ
60
Io
3.8
3.6
1
1.2
S12 changing only in α6

312 Mev

FIG. 5


4.7
312 Mev
S12 changing in a^δ and δ_δ^J
4.3
Io
3.9
.4
1
1.2
1.6
3.5
0°
30°
θ
60°
90°

APPENDIX A

$$M_{11} = \langle 11 | M | 11 \rangle,$$

where $|11\rangle$ is the state with both spins up, with reference to the axis of quantisation, and

$$M = a + ic\,(\underline{\sigma}^1 + \underline{\sigma}^2).\underline{N} + m\,(\underline{\sigma}^1.\underline{N}\,\underline{\sigma}^2.\underline{N}) +$$

$$(g + h)\,\underline{\sigma}^1.\,\underline{P}.\,\underline{\sigma}^2.\underline{P} + (g-h)(\underline{\sigma}^1.\,\underline{K}\,\underline{\sigma}^2.\underline{K}) \qquad \text{(I-11)}$$

with $\underline{k}$ in the positive z direction,

$$\underline{k} = (\;0 \quad 0 \quad 1\;)$$

$$\underline{k}' = (\sin\theta\cos\phi,\ \sin\theta\sin\phi,\ \cos\theta)$$

$$\underline{k}\times\underline{k}' = \underline{j}\,(k_x') - \underline{i}\,(k_y')$$

$$= \underline{j}\sin\theta\cos\phi - \underline{i}\sin\theta\sin\phi$$

Therefore,

$$\underline{N} = \underline{j}\cos\phi - \underline{i}\sin\phi$$

$$\underline{P} = \sin\frac{\theta}{2}\,(\underline{i}\cos\phi + \underline{j}\sin\phi) + \underline{k}\cos\frac{\theta}{2}$$

$$\underline{K} = \cos\frac{\theta}{2}\,(\underline{i}\cos\phi + \underline{j}\sin\phi) - \underline{k}\sin\frac{\theta}{2}$$

Now, considering each term in (I-11), in turn, it follows that:

$$\langle 11 | a | 11 \rangle = a \qquad (1)$$

$$\langle 11 | ic\,(\underline{\sigma}^1 + \underline{\sigma}^2).\,\underline{N} | 11 \rangle = 0, \qquad (2)$$

where the value of $\underline{N}$ is substituted and use has been made of:

$$\sigma_x |1\rangle = |-1\rangle, \qquad \sigma_x |-1\rangle = |1\rangle$$

$$\sigma_y |1\rangle = i|-1\rangle, \qquad \sigma_y |-1\rangle = -i|1\rangle, \text{ and}$$

$$\sigma_z |1\rangle = |1\rangle, \qquad \sigma_z |-1\rangle = -|-1\rangle; \tag{3}$$

$|1\rangle$ and $|-1\rangle$ describe the spin of proton being up and down, respectively. For the similar reasons

$$\langle 11 | m \underline{\sigma}^1 . \underline{N} \underline{\sigma}^2 . \underline{N} | 11 \rangle = 0 \tag{4}$$

Also since

$$\underline{\sigma}^2 . \underline{P} |11\rangle = \sin\frac{\theta}{2} e^{i\phi} | 1-1\rangle + \cos\frac{\theta}{2} | 11\rangle,$$

it is seen that

$$\langle 11 | (g+h) \underline{\sigma}^1 . \underline{P} \underline{\sigma}^2 . \underline{P} | 11\rangle = (g+h) \cos^2 \frac{\theta}{2} \tag{5}$$

Similarly,

$$\langle 11 | (g-h) \underline{\sigma}^1 . \underline{K} \underline{\sigma}^2 . \underline{K} | 11\rangle = (g-h) \sin^2 \frac{\theta}{2} \tag{6}$$

By combining (1), (2), (4), (5), and (6) it is obvious that

$$M_{11} = a + g + h \cos\theta.$$

APPENDIX B

```
C     P-P SCATTERING I

      DIMENSION CA%8□,CB%8□,CC%8□,A%6□,B%6□,C%6□,Y2%6□,P%8□,PF%8□,PS%8□,
     2X2%6□,X3%6□,X4%6□,X5%6□,X6%6□,              SX1%10□,SX2%10□,SX3%10□,
     4SX4%10□,SX5%10□,SX6%10□,SY1%10□,SY2%10□,SY3%10□,SY4%10□,SY5%10□,
     5SY6%10□
      EQUIVALENCE %CC%1□,D□,%CC%3□,E□,%CA%7□,G□,%CC%7□,H□,%CC%8□,Q□,
     1%CB%1□,R□,%CB%8□,GU□,%B%3□,PI□,%C%3□,EN□,%B%5□,AA□,%C%5□,CO□,
     2%PF%1□,CMB□,%PF%3□,ETA□,%PF%5□,F□,%PF%7□,S□,%PS%1□,BC□,%PS%3□,CS□,
     3%PS%5□,SN□,%PS%7□,T□
      DO 62 M # 1,6
      X2%M□#0.0
      X3%M□#0.0
      X4%M□#0.0
      X5%M□#0.0
      X6%M□#0.0
      Y2%M□#0.0
      A%M□#0.0
      B%M□#0.0
   62 C%M□#0.0
      PI # 3.1415927
      DO 1 M # 1,8
    1 READ 10,CA%M□,CB%M□,CC%M□
      READ 10,EN,BC,CO
   10 FORMAT %3F10.7□
      Z#SQRTF%1.2049*EN□
      TEST#0.5
      L#1
  101 I # 1
      DO 99 KH # 1,10
      AA#KH-1
      IF %AA□ 67,66,67
   66 AA#0.1
   67 IF %AA-9.0□ 64,65,64
   65 AA#8.9
   64 AA#%PI*AA□/18.0
      X#COSF%AA□
      P%1□#1.0
      P%2□#X
      PF%1□#0.0
      PF%2□#1.0
      PS%1□#0.0
      PS%2□#0.0
```

```
      PS%3□#3.0*%1.0-X*X□
      DO 12 M#3,8
      T # M-1
      GU # %2.0*T-1.0□*X
      P%M□#%GU*P%M-1□-%T-1.0□*P%M-2□□/T
      IF %M-3□ 12,12,13
   13 PS%M□#%GU*PS%M-1□-%T&1.0□*PS%M-2□□/%T-2.0□
   12 PF%M□#%GU*PF%M-1□-T*PF%M-2□□/%T-1.0□
      CMB#0.0
      DO 4 M # 1,5,2
      T # M-1
      A%M□#2.0*%CA%M□&CMB□
      GU#%2.0*T&1.0□*P%M□
      CS#COSF%2.0*CMB□
      SN#SINF%2.0*CMB□
      X2%M□#GU*%COSF%A%M□□-CS□
      X2%3□#5.0*P%3□*%D*COSF%A%3□□-CS□
      Y2%M□#GU*%SINF%A%M□□-SN□
      Y2%3□#5.0*P%3□*%D*SINF%A%3□□-SN□
    4 CMB#CMB&ATANF%CO/%T&2.0□□&ATANF%CO/%T&1.0□□
      ETA#0.0
  105 CMB#ATANF%CO□
      DO 7 M#2,6,2
      T#M - 1
      CMB#ATANF%CO/T□
      Q#CB%M&1□*SQRTF%%T&1.0□*%T&2.0□□
      R#CB%M-1□*SQRTF%T*%T-1.0□□
      CS#COSF%2.0*CMB□
      SN#SINF%2.0*CMB□
      G#SQRTF%1.0-CB%M-1□*CB%M-1□□
      H#SQRTF%1.0-CB%M&1□*CB%M&1□□
      A%M□#2.0*%CA%M□&CMB□
      B%M□#2.0*%CB%M□&CMB□
      C%M□#2.0*%CC%M□&CMB□
      IF %ETA□ 92,92,91
   92 A%M□#G*COSF%A%M□□-CS
      B%M□#COSF%B%M□□-CS
      C%M□#H*COSF%C%M□□-CS
      F# -SINF%CC%2□&CA%4□□*Q*SQRTF%E□
      S#0.0
      GU#%2.0*T&1.0□/%T*%T&1.0□□
      C%2□#SQRTF%1.0-CB%3□*CB%3□□*E*COSF%2.0*%CC%2□&CMB□□-CS
      C%6□#0.0
      GO TO 93
   91 A%M□#G*SINF%A%M□□-SN
      B%M□#SINF%B%M□□-SN
      C%M□#H*SINF%C%M□□-SN
      F#  COSF%CC%2□&CA%4□□*Q*SQRTF%E□
      S#0.0
      GU#%2.0*T&1.0□/%T*%T&1.0□□
      C%2□#SQRTF%1.0-CB%3□*CB%3□□*E*SINF%2.0*%CC%2□&CMB□□-SN
      C%6□#CB%7□
   93 IF %ETA□ 95,95,94
   95 IF %M-4□ 6,5,9
    9 F#0.0
```

```
      S# -SINF%CC%M-2□&CA%M□□*R
      GO TO 96
    5 S# -SINF%CC%M-2□&CA%M□□*R*SQRTF%E□
      F# -SINF%CC%M□&CA%M&2□□*Q
      GO TO 96
   94 IF %M-4□ 6,97,98
   98 F#BC*SQRTF%42.0□
      S#  COSF%CC%M-2□&CA%M□□*R
      GO TO 96
   97 S#  COSF%CC%M-2□&CA%M□□*R*SQRTF%E□
      F#  COSF%CC%M□&CA%M&2□□*Q
   96 X6%M□#C%M□/%T&1.0□-GU*B%M□&A%M□/T-F/%%T&1.0□*%T&2.0□□
      X6%M□#%X6%M□-S/%T*%T-1.0□□□*PS%M□/2.0
    6 X2%M□#%%T&2.0□*C%M□&%2.0*T&1.0□*B%M□&%T-1.0□*A%M□-F-S□*P%M□/2.0
      X3%M□#%%T&1.0□*C%M□&T*A%M□&F&S□*P%M□
      X4%M□#GU*B%M□&%T-1.0□*A%M□/T-%T&2.0□*C%M□/%T&1.0□
      X4%M□#%X4%M□&F/%T&1.0□-S/T□*PF%M□
      X5%M□#%C%M□-A%M□&F/%T&1.0□-S/T□*PF%M□
    7 CMB#CMB&ATANF%CO/%T&2.0□□&ATANF%CO/%T&1.0□□
      IF %ETA□ 103,103,104
  103 SX1%I□ # X2%1□&X2%3□&X2%5□
      SX2%I□ # X2%2□&X2%4□&X2%6□
      SX3%I□ # X3%2□&X3%4□&X3%6□
      SX4%I□ # X4%2□&X4%4□&X4%6□
      SX5%I□ # X5%2□&X5%4□&X5%6□
      SX6%I□ # X6%2□&X6%4□&X6%6□
      ETA#1.0
      GO TO 105
  104 SY1%I□#Y2%1□&Y2%3□&Y2%5□
      SY2%I□#X2%2□&X2%4□&X2%6□-F*P%8□/2.0
      SY3%I□#X3%2□&X3%4□&X3%6□&F*P%8□
      SY4%I□#X4%2□&X4%4□&X4%6□-F*PF%8□/7.0
      SY5%I□#X5%2□&X5%4□&X5%6□-F*PF%8□/7.0
      SY6%I□#X6%2□&X6%4□&X6%6□-F*PS%8□/84.0
      DO 8 J # 1,2
      GU#1.0-COSF%AA□
      ETA#CO*LOGF%GU/2.0□
      X2%J□# -%CO*SINF%ETA□□/GU
      Y2%J□# -%CO*COSF%ETA□□/GU
    8 AA#PI - AA
      ETA#Y2%1□&Y2%2□
      AA#Y2%1□-Y2%2□
      M#L&1
      GU#SQRTF%%1.0-X*X□/2.0□/Z
      IF %TEST-1.0□ 49,51,51
   49 SX1%I□#%SY1%I□&ETA□/Z
      SX2%I□#%SY2%I□&AA□/Z
      SX3%I□#%SY3%I□&AA□/Z
      SX4%I  □#SY4%I□*GU
      SX5%I  □#SY5%I□*GU
      SX6%I  □#SY6%I□/Z
      PUNCH 800, SX1%I□,SX2%I□,SX3%I□,I,L,SX4%I□,SX5%I□,SX6%I□,I,M
      GO TO 550
   51 ETA#X2%1□&X2%2□
      AA#X2%1□-X2%2□
```

```
      SY1%I¤# - %SX1%I¤&ETA¤/Z
      SY2%I¤# - %SX2%I¤&AA¤/Z
      SY3%I¤# - %SX3%I¤&AA¤/Z
      SY4%I¤# - SX4%I¤*GU
      SY5%I¤# - SX5%I¤*GU
      SY6%I¤# - SX6%I  ¤/Z
      PUNCH 800, SY1%I¤,SY2%I¤,SY3%I¤,I,L,SY4%I¤,SY5%I¤,SY6%I¤,I,M
  550 L#L&2
   99 I # I & 1
      IF %TEST-1.0¤ 54,55,55
   54 TEST # TEST&1.0
      GO TO 101
  800 FORMAT %3F24.8,2I4¤
   55 PUNCH 800,EN,Z,CO
      STOP
      END
```

CD TOT 0194

```
C       P-P SCATTERING II

        DIMENSION CX%10□,SX5%10□,SX6%10□,Q%10□,P%8□,PF%8□,PS%8□,
       1          SY1%10□,SY2%10□,SY3%10□,SY4%10□,SY5%10□,SY6%10□,
       2AY%10□,CY%10□,YM%10□,GY%10□,HY%10□,SX1%10□,SX2%10□,SX3%10□,SX4%10□
        READ 2,EN
    2 FORMAT %F5.2□
        Z#SQRTF%1.2049*EN□
        W#0.13963*5.06804
        W#W*W
        Y#1.0&%W/%2.0*Z*Z□□
        PI # 3.1415927
        TEST # 0.5
  800 FORMAT %3F24.8□
        DO 550 I # 1,10
  550 READ  800,SX1%I□,SX2%I□,SX3%I□,SX4%I□,SX5%I□,SX6%I□
        DO 560 I # 1,10
  560 READ 800,SY1%I□,SY2%I□,SY3%I□,SY4%I□,SY5%I□,SY6%I□
        PUNCH 30
   30 FORMAT %37HFOLLOWING IS MIJ PP YLAM WITH NO OPEP□
        PUNCH 60
   60 FORMAT%15X,4HXMSS,14X,4HYMSS,14X,4HXM11,14X,4HYM11□
        DO 16 I#1,10
   16 PUNCH 500,I,SX1%I□,SY1%I□,SX2%I□,SY2%I□
        PUNCH 70
   70 FORMAT%15X,4HXM00,14X,4HYM00,13X,5HXM1M1,13X,5HYM1M1□
        DO 17 I#1,10
   17 PUNCH 500,I,SX3%I□,SY3%I□,SX6%I□,SY6%I□
        PUNCH 80
   80 FORMAT%15X,4HXM01,14X,4HYM01,14X,4HXM10,14X,4HYM10□
        DO 14 I # 1,10
   14 PUNCH 500,I,SX4%I□,SY4%I□,SX5%I□,SY5%I□
        ACCEPT 2,G
        CE#%Y&1.0□/%Y-1.0□
        Q%1□#LOGF%CE□/2.0
        Q%2□#Y*Q%1□ - 1.0
        DO 12 M#3,10
        T # M-1
   12 Q%M□#%%2.0*T-1.0□*Y*Q%M-1□-%T-1.0□*Q%M-2□□/T
        E#SQRTF%%4.7549*4.7549□&%Z*Z□□
        CE # - %G*W□/%12.0*E*Z□
  101 I#1
        DO 99 KH # 1,10
        AA#KH-1
        IF %KH-1□ 67,66,67
   66 AA#0.1
   67 IF %AA-9.0□ 64,65,64
   65 AA#8.9
   64 AA#%PI*AA□/18.0
        X#COSF%AA□
        AAL#ATANF%4.7549*SQRTF%%1.0-X□/%1.0&X□□/E□
        PHL#ATANF%4.7549*SQRTF%%1.0&X□/%1.0-X□□/E□
        AA#-AAL&AA/2.0
        AAL#-AA-AAL-PHL&PI/2.0
        L#43
        PUNCH 990,AA,AAL,X,1,L
        SQ#1.0-X*X
```

```
      P%1□#1.0
      P%2□ # X
      PF%1□#0.0
      PF%2□#1.0
      PS%1□#0.0
      PS%2□#0.0
      PS%3□#3.0*%1.0-X*X□
      DO 7 M#3,8
      T # M-1
      T2 # %2.0*T-1.0□*X
      P%M□#%T2*P%M-1□-%T-1.0□*P%M-2□□/T
      IF %M-3□ 7,7,13
   13 PS%M□#%T2*PS%M-1□-%T&1.0□*PS%M-2□□/%T-2.0□
    7 PF%M□#%T2*PF%M-1□-T*PF%M-2□□/%T-1.0□
      L#44
      DO 670 M#1,8
      PUNCH 990,P%M□,PF%M□,PS%M□,I,L
  670 L#L&1
      AY%I□#%2.0*SY2%I□ & SY3%I□ & SY1%I□□/4.0
      CY%I□#%SY5%I□ - SY4%I□□/SQRTF%8.0□
      YM%I□#%SY3%I□ - 2.0*SY6%I□ - SY1%I□□/4.0
      GY%I□#%SY2%I□ & SY6%I□ - SY1%I□□/4.0
      HY%I□#%SY2%I□ - SY3%I□ - SY6%I□□/%4.0*X□
      AL#%1.0&X□/%Y&X□
      BE#%1.0-X□/%Y-X□
      PX1# - %G*%AL&BE□□/%4.0*E□
      PX2# - %G  *%%1.0&X□*AL - BE*%1.0-X□□□/%8.0*E□
      PX3# -PX1*X
      PX4#-%G*%AL&BE□*SQRTF%SQ/8.0□□/%2.0*E□
      PX6# - %G  *%AL*%1.0 - X□ - %1.0 & X□*BE□□/%8.0*E□
      PUNCH 300,PX1,PX2,PX3,PX4,PX6,I
      SX1%I□#SX1%I□&PX1
      SX2%I□#SX2%I□&PX2
      SX3%I□#SX3%I□&PX3
      SX4%I□#SX4%I□&PX4
      SX5%I□#SX5%I□&PX4
      SX6%I□#SX6%I□&PX6
   99 I # I&1
      L#1
      DO 660 I # 1,10
      M#L&1
      N#L&2
      J#L&3
      PUNCH 990,AY%I□,CY%I□,YM%I□,I,L,GY%I□,HY%I□,Q%I□,I,M,SX1%I□,
     1SX2%I□,SX3%I□,I,N,SX4%I□,SX5%I□,SX6%I□,I,J
  660 L#L&4
      M#L&1
      PUNCH 990,Z,E,G,L,L,W,Y,CE,M,M
      PUNCH 100
  100 FORMAT%12X,2HYA,13X,2HYC,13X,2HYM,13X,2HYG,13X,2HYH□
      DO 15 I # 1,10
   15 PUNCH 300,AY%I□,CY%I□,YM%I□,GY%I□,HY%I□,I
  300 FORMAT %5F15.5,I5□
  500 FORMAT %I3,4F18.5□
  990 FORMAT %3F24.8,2I4□
      STOP
      END
```

```
C      P-P SCATTERING III
       DIMENSION A%8□,B%8□,P%8□,PF%8□,PS%8□,Q%10□,
      2        X1%6□,X2%6□,X3%6□,X4%6□,X5%6□,X6%6□, S%8□,SX4%11□,
      3AY%10□,CY%10□,YM%10□,GY%10□,HY%10□,SX1%11□,SX2%11□,SX3%11□,
      4SX5%11□,SX6%11□ ,POL%10,5□ ,S12%5□
       EQUIVALENCE %X2%1□,TEST□,%X3%1□,ALT□,%X4%1□,X3S□,%X5%1□,X4S□,
      1%X6%1□,GU□,%B%8□,RAM□,%S%7□,SHV□,%S%5□,STA□,%S%3□,RA□,%S%1□,SH□,
      2%X2%5□,C□,%X3%5□,V□,%X4%5□,F□
       PI#3.1415927
       DO 29 M#1,6
       X1%M□#0.0
       X2%M□#0.0
       X3%M□#0.0
       X4%M□#0.0
       X5%M□#0.0
       X6%M□#0.0
       A%M□#0.0
       B%M□#0.0
   29  S%M□#0.0
       A%7□#0.0
       A%8□#0.0
       B%7□#0.0
       B%8□#0.0
       S%7□#0.0
       S%8□#0.0
       TEST#0.0
       READ 10,ALT,AL,BE,GA
   10  FORMAT %4F5.2□
       DO 660 I # 1,10
  660  READ 990,AY%I□,CY%I□,YM%I□,GY%I□,HY%I□,Q%I□,SX1%I□,SX2%I□,SX3%I□,
      1SX4%I□,SX5%I□,SX6%I□
       READ 990,Z,E,G,W,Y,CE,CB
       PUNCH 990,Z,E,G
  990  FORMAT %3F24.8□
       L#1
  101  I # 1
       DO 99 KH # 1,10
       READ 990,AA,AAL,X
       DO 670 M#1,8
  670  READ 990,P%M□,PF%M□,PS%M□
       DO 21 M#3,5,2
       T#M-1
       X1%M□#%2.0*T&1.0□*P%M□
   21  X1%M□#X1%M□  * %G*%Y-1.0□*Q%M□□/%2.0*E□
       X1%1□#                   G   *%%Y-1.0□*Q%1□ - 1.0□/%2.0*E□
       J#1
       DO 98 KB#6,14,2
       DO 23 M # 2,6,2
       DO 19 N#2,8,2
       T#N-1
       S%N□# Q%N□&3.0*Z*Z*%Q%N-1□ - Q%N&1□□/%W*%2.0*T&1.0□□
       A%N□#CE*%Q%N□ - %2.0*%T&1.0□*S%N□□/%2.0*T - 1.0□□
   19  S%N□#CE*%Q%N□ - %2.0*T*S%N□□/%2.0*T&3.0□□
```

```
   T#M-1
   GU#%2.0*T&1.0□/%T*%T&1.0□□
   X3S#0.0
   X4S#0.0
   IF %M-4□ 31,32,32
32 AR#CR
   X3S#T*%T-1.0□*AR
   X4S# - %T-1.0□*AR
31 CR#A%M&2□-S%M□
   S12%J□#KB
   DO 22 N#2,8,2
   T#N-1
   U#KB
   IF %N-6□ 51,53,51
53 IF %ALT-1.0□ 52,51,51
51 U#10.0
52 S%N□#%Q%N□&3.0*Z*Z*%Q%N-1□ - Q%N&1□□/%W*%2.0*T&1.0□□□*U/10.0
   A%N□#CE*%Q%N□ - %2.0*%T&1.0□*S%N□□/%2.0*T - 1.0□□
   B%N□#CE*%Q%N□ & 2.0*S%N□□
22 S%N□#CE*%Q%N□ - %2.0*T*S%N□□/%2.0*T&3.0□□
   T#M-1
   IF %M-4□ 24,25,26
26 CR#%CB*%AL&BE*S12%J□□□ /%GA*SQRTF%42.0□□
25 X6%M□#%%S%M□/%T&1.0□□&%A%M□/T□ - %GU*B%M□&AR&CR□□*PS%M□/2.0
24 X2%M□#              &%%2.0*T&1.0□*B%M□□&%%T-1.0□*A%M□□&%T&2.0□*S%M□
   X2%M□#%X2%M□-X3S- %T&1.0□*%T&2.0□*CR□*P%M□/2.0
   X3%M□#%%%T&1.0□*S%M□□&%T*A%M□□&%%T&1.0□*%T&2.0□*CR□&X3S□*P%M□
   X4%M□#GU*B%M□ - %S%M□*%T&2.0□/%T&1.0□□
   X4%M□#%X4%M□ &%%T-1.0□*A%M□/T□&%T&2.0□*CR&%X4S□□*PF%M□
23 X5%M□#%S%M□ - A%M□ & %%T&2.0□*CR□ & X4S□*PF%M□
   K#11
   GU#SQRTF%%1.0-X*X□/2.0□/Z
   X1%4□#X1%1□&X1%3□&X1%5□
   X2%3□#%X2%2□&X2%4□&X2%6□-21.0*CR*P%8□□/Z
   X3%3□#%X3%2□&X3%4□&X3%6□&42.0*CR*P%8□□/Z
   X4%3□#%X4%2□&X4%4□&X4%6□-6.0*CR*PF%8□□*GU
   X5%3□#%X5%2□&X5%4□&X5%6□-6.0*CR*PF%8□□*GU
   X6%3□#%X6%2□&X6%4□&X6%6□-0.5*CR*PS%8□□/Z
   SX1%K□#SX1%I□-X1%4□
   SX2%K□#SX2%I□-X2%3□
   SX3%K□#SX3%I□-X3%3□
   SX4%K□#SX4%I□-X4%3□
   SX5%K□#SX5%I□-X5%3□
   SX6%K□#SX6%I□-X6%3□
   X3S#0.0
   T#AY%I□
   U#GY%I□
   V#YM%I□
68 AX    #%2.0*SX2%K□&SX3%K□&SX1%K□□/4.0
   CX    #%SX5%K□-SX4%K□□/SQRTF%8.0□
   XM    #%SX3%K□-2.0*SX6%K□-SX1%K□□/4.0
   GX    #%SX2%K□&SX6%K□-SX1%K□□/4.0
   HX    #%SX2%K□-SX3%K□-SX6%K□□/%4.0*X□
   SHV#AX
   RAM#CX
```

```
      STA#GX
      RA#CX*HX
      X4S#HX
      GU#XM
      C#CY%I¤
      F#HY%I¤
      CR#%%AX-XM¤*GX&%T-V¤*U¤*2.0
      AR#%%AX&XM¤*HX&%T&V¤*F¤*2.0
      SX4%K¤# -%CX*HX&C*F¤*4.0
      SX5%K¤#AX*XM&T*V
      AX#AX*AX
      CX#CX*CX
      GX#GX*GX
      XM#XM*XM
      HX#HX*HX
      T#T*T
      C#C*C
      V#V*V
      U#U*U
      F#F*F
      SX1%K¤#AX&T&XM&V&2.0*%CX&C&GX&U&HX&F¤
      SX2%K¤#2.0*%CX&C-GX-U-HX-F¤&AX&T&XM&V
      SX3%K¤#SX1%K¤ - SX2%K¤
      SX2%K¤#SX2%K¤/SX1%K¤
      IF %X3S-1.0¤ 113,113,115
  113 IF %TEST-2.0¤ 114,117,118
  114 PUNCH 990,X
      PUNCH 110
  110 FORMAT%7X,3HS12,10X,2HI0,10X,1HD,7X,5HI01MD,10X;2HHX,7X,5H   XM¤
      PUNCH 90
   90 FORMAT%19X,2HAX,22X,2HCX,22X,2HGX¤
      TEST#2.0
  117 S12#S12/10.0
      PUNCH 600,S12,SX1%K¤,SX2%K¤,SX3%K¤,X4S,GU    ,I,L
      L#L&1
      PUNCH 700,SHV,RAM,STA,I,L
      L#L&1
      GO TO 98
  118 IF %TEST-6.0¤ 116,119,119
  116 PUNCH 990,X
      PUNCH 120
  120 FORMAT%7X,3HS12,7X,5HCX HX,7X,5H  CKP,7X,5H  CNN,7X,5H  CKK,8X,
     14HPPPP¤
      PUNCH 130
  130 FORMAT%8X,1HD,8X,5HI01MD,8X,4HRCKP,8X,4HPDIF,8X,4HRCKK,8X,4HPDIF¤
      TEST#6.0
  119 S12#S12/10.0
      SX5%K¤#%SX5%K¤&CX&C-GX-U&HX&F¤*2.0
      SX6%K¤#CR-AR
      HX#2.0*%GX&U&HX&F-CX-C¤&AX&T&XM&V
      AX#SX4%K¤
      CX#SX1%K¤
      AX#AX/CX
      SX5%K¤#SX5%K¤/CX
      SX6%K¤#SX6%K¤/CX
```

```
      L#L&1
      S12#SX4%K□*COSF%AAL-AA□-CR*SINF%AAL&AA□&AR*SINF%AAL-AA□
      SH#CR*COSF%AAL&AA□-AR*COSF%AAL-AA□&SX4%K□*SINF%AAL-AA□
      S12#S12/CX
      SH#SH/CX
      X5%5□#%S12-AX□*100.0/S12
      X6%5□#%SH-SX6%K□□*100.0/SH
      SX1%K□#SX1%I□-X1%4□
      SX4%K□#SX4%I□-X4%3□
      SX5%K□#SX5%I□-X5%3□
      SX2%K□# -SX2%I□&X2%3□
      SX3%K□# -SX3%I□&X3%3□
      SX6%K□# -SX6%I□&X6%3□
      T# -%AY%I□&YM%I□□/2.0
      V#T&GY%I□
      T#T-GY%I□
      U#%YM%I□-AY%I□□/2.0
      X3S#2.0
      GO TO 68
  115 PUNCH 800,SX2%K□,SX3%K□,S12,X5%5□,SH,X6%5□,I,L
      L#L&1
   98 CONTINUE
      TEST#TEST-2.0
   99 I#I&1
      TEST#TEST&3.0
      IF %I-10□ 101,505,505
  600 FORMAT%6F12.5,2I4□
  700 FORMAT %3F24.8,2I4□
  800 FORMAT %6F12.5,2I4/□
  505 STOP
      END
```

APPENDIX C

312 MEV OBSERVABLES, AND SCATTERING MATRIX REAL WITH OPEP

OPEP TENSOR FORCE CHANGING IN L#5 PHASES AND IN ALPHA 6
COULOMB INTERACTION INCLUDED

	.99984769						
S12	IO	D	IO1MD	HX	XM		
	AX		CX		GX	1°	
.20000	1057.03980	.99955	.46380	-.04541	-.27416	1	1
	-32.40090200		.00972558		-.31792975	1	2
.40000	1057.04010	.99955	.46540	-.04672	-.27324	1	3
	-32.40090200		.00972558		-.31838873	1	4
.60000	1057.04040	.99955	.46710	-.04804	-.27232	1	5
	-32.40090200		.00972558		-.31884775	1	6
.80000	1057.04080	.99955	.46880	-.04936	-.27141	1	7
	-32.40090200		.00972558		-.31930675	1	8
1.00000	1057.04110	.99955	.47040	-.05068	-.27049	1	9
	-32.40090200		.00972558		-.31976600	1	10
1.20000	1057.04150	.99955	.47220	-.05200	-.26957	1	11
	-32.40090200		.00972558		-.32022500	1	12
1.40000	1057.04190	.99955	.47400	-.05332	-.26865	1	13
	-32.40090200		.00972558		-.32068400	1	14
1.60000	1057.04220	.99955	.47560	-.05464	-.26773	1	15
	-32.40090200		.00972558		-.32114325	1	16

	.98480775						
S12	IO	D	101MD	HX	XM		
	AX		CX		GX	10°	
.20000	.40613	.15828	.34184	-.11053	-.26986	2	17
	-.17144447		.09572033		-.24654463	2	18
.40000	.40552	.15254	.34366	-.10942	-.26704	2	19
	-.17144447		.09572033		-.24795741	2	20
.60000	.40494	.14677	.34551	-.10831	-.26421	2	21
	-.17144447		.09572034		-.24937020	2	22
.80000	.40439	.14098	.34738	-.10720	-.26139	2	23
	-.17144447		.09572033		-.25078297	2	24
1.00000	.40387	.13518	.34928	-.10609	-.25856	2	25
	-.17144447		.09572034		-.25219575	2	26
1.20000	.40338	.12936	.35120	-.10498	-.25574	2	27
	-.17144452		.09572034		-.25360857	2	28
1.40000	.40292	.12352	.35315	-.10388	-.25291	2	29
	-.17144447		.09572033		-.25502132	2	30
1.60000	.40248	.11767	.35512	-.10277	-.25008	2	31
	-.17144447		.09572034		-.25643412	2	32

.93969262

S12	IO AX	D	IO1MD CX	HX	XM GX	20°	
.20000	.37904	.25921	.28079	-.20754	-.25171	3	33
	.04906367		.18251986		-.12511180	3	34
.40000	.37256	.26238	.27480	-.20170	-.24468	3	35
	.04906368		.18251986		-.12862539	3	36
.60000	.36636	.26522	.26919	-.19587	-.23766	3	37
	.04906366		.18251986		-.13213899	3	38
.80000	.36045	.26771	.26395	-.19004	-.23063	3	39
	.04906367		.18251986		-.13565257	3	40
1.00000	.35483	.26983	.25908	-.18421	-.22360	3	41
	.04906366		.18251986		-.13916617	3	42
1.20000	.34948	.27154	.25458	-.17837	-.21657	3	43
	.04906364		.18251986		-.14267977	3	44
1.40000	.34443	.27282	.25046	-.17254	-.20955	3	45
	.04906363		.18251986		-.14619337	3	46
1.60000	.33965	.27366	.24670	-.16671	-.20252	3	47
	.04906367		.18251986		-.14970694	3	48

.86602540

S12	IO AX	D	IO1MD CX	HX	XM GX	30°	
.20000	.40557	.27725	.29313	-.24920	-.20912	4	49
	.05591620		.25326001		-.03237384	4	50
.40000	.39476	.29170	.27960	-.24161	-.19919	4	51
	.05591618		.25326001		-.03733750	4	52
.60000	.38447	.30621	.26674	-.23402	-.18926	4	53
	.05591616		.25326000		-.04230118	4	54
.80000	.37471	.32071	.25453	-.22642	-.17933	4	55
	.05591620		.25326001		-.04726483	4	56
1.00000	.36547	.33514	.24298	-.21883	-.16941	4	57
	.05591618		.25326001		-.05222849	4	58
1.20000	.35676	.34944	.23209	-.21124	-.15948	4	59
	.05591619		.25326001		-.05719215	4	60
1.40000	.34858	.36352	.22186	-.20364	-.14955	4	61
	.05591619		.25326001		-.06215580	4	62
1.60000	.34092	.37730	.21229	-.19605	-.13962	4	63
	.05591620		.25326000		-.06711946	4	64

.76604447

S12	IO AX	D	IO1MD CX	HX	XM GX	40°	
.20000	.39250	.34236	.25812	-.23467	-.13679	5	65
	.02326069		.30397878		.02771815	5	66
.40000	.38613	.35268	.24995	-.23075	-.12816	5	67
	.02326070		.30397879		.02340275	5	68
.60000	.38004	.36310	.24204	-.22683	-.11953	5	69
	.02326071		.30397880		.01908733	5	70
.80000	.37424	.37361	.23441	-.22292	-.11090	5	71
	.02326072		.30397880		.01477192	5	72
1.00000	.36872	.38419	.22706	-.21900	-.10227	5	73
	.02326070		.30397881		.01045651	5	74
1.20000	.36348	.39482	.21997	-.21508	-.09364	5	75
	.02326071		.30397881		.00614110	5	76
1.40000	.35853	.40548	.21315	-.21117	-.08500	5	77
	.02326072		.30397879		.00182569	5	78

1.60000	.35387	.41613	.20661	-.20725	-.07637		5	79
	.02326075		.30397881		-.00248970		5	80
	.64278762							
S12	IO	D	IO1MD	HX	XM			
	AX		CX		GX	50°		
.20000	.36081	.46161	.19425	-.19264	-.04325		6	81
	-.02222046		.33456043		.06455091		6	82
.40000	.36191	.45570	.19698	-.19492	-.04010		6	83
	-.02222095		.33456044		.06297454		6	84
.60000	.36306	.44973	.19978	-.19720	-.03695		6	85
	-.02222096		.33456042		.06139816		6	86
.80000	.36427	.44371	.20264	-.19948	-.03380		6	87
	-.02222095		.33456042		.05982179		6	88
1.00000	.36552	.43764	.20555	-.20177	-.03064		6	89
	-.02222095		.33456044		.05824542		6	90
1.20000	.36683	.43152	.20853	-.20405	-.02749		6	91
	-.02222095		.33456042		.05666905		6	92
1.40000	.36819	.42535	.21157	-.20633	-.02434		6	93
	-.02222095		.33456043		.05509268		6	94
1.60000	.36960	.41915	.21468	-.20861	-.02119		6	95
	-.02222095		.33456041		.05351631		6	96
	.50000004							
S12	IO	D	IO1MD	HX	XM			
	AX		CX		GX	60°		
.20000	.34728	.55735	.15372	-.15699	.04987		7	97
	-.06860178		.34846620		.08874744		7	98
.40000	.35106	.53868	.16195	-.16247	.04644		7	99
	-.06860177		.34846621		.09046129		7	100
.60000	.35500	.51988	.17044	-.16794	.04301		7	101
	-.06860177		.34846619		.09217514		7	102
.80000	.35909	.50097	.17919	-.17342	.03958		7	103
	-.06860177		.34846619		.09388900		7	104
1.00000	.36334	.48198	.18821	-.17890	.03616		7	105
	-.06860178		.34846620		.09560285		7	106
1.20000	.36775	.46294	.19750	-.18438	.03273		7	107
	-.06860178		.34846622		.09731670		7	108
1.40000	.37231	.44388	.20705	-.18986	.02930		7	109
	-.06860177		.34846619		.09903055		7	110
1.60000	.37703	.42482	.21686	-.19534	.02587		7	111
	-.06860178		.34846621		.10074441		7	112
	.34202021							
S12	IO	D	IO1MD	HX	XM			
	AX		CX		GX	70°		
.20000	.35719	.57656	.15124	-.14603	.11822		8	113
	-.10756800		.35153119		.10930143		8	114
.40000	.35889	.56005	.15789	-.14901	.11118		8	115
	-.10756800		.35153119		.11282208		8	116
.60000	.36079	.54346	.16471	-.15190	.10414		8	117
	-.10756799		.35153119		.11634273		8	118
.80000	.36286	.52682	.17170	-.15498	.09710		8	119
	-.10756799		.35153120		.11986338		8	120
1.00000	.36513	.51014	.17896	-.15796	.09005		8	121
	-.10756799		.35153118		.12338403		8	122
1.20000	.36757	.49346	.18619	-.16094	.08301		8	123
	-.10756800		.35153118		.12690468		8	124

1.40000	.37020	.47680	.19369	-.16392	.07597	8 125
	-.10756800		.35153119		.13042533	8 126
1.60000	.37302	.46018	.20136	-.16691	.06893	8 127
	-.10756800		.35153120		.13394598	8 128
	.17364828					
S12	IO	D	IO1MD	HX	XM	
	AX		CX		GX	80°
.20000	.37457	.53627	.17369	-.15321	.14797	9 129
	-.13339812		.35010041		.12918882	9 130
.40000	.37296	.53438	.17365	-.15083	.14249	9 131
	-.13339812		.35010043		.13192884	9 132
.60000	.37246	.53233	.17371	-.14844	.13701	9 133
	-.13339812		.35010043		.13466887	9 134
.80000	.37007	.53012	.17388	-.14605	.13153	9 135
	-.13339812		.35010041		.13740889	9 136
1.00000	.36879	.52776	.17416	-.14366	.12605	9 137
	-.13339812		.35010041		.14014892	9 138
1.20000	.36763	.52523	.17454	-.14127	.12057	9 139
	-.13339813		.35010043		.14288894	9 140
1.40000	.36658	.52255	.17502	-.13888	.11509	9 141
	-.13339813		.35010043		.14562897	9 142
1.60000	.36565	.51971	.17561	-.13650	.10961	9 143
	-.13339813		.35010043		.14836899	9 144
	.01745244					
S12	IO	D	IO1MD	HX	XM	
	AX		CX		GX	89°
.20000	.38265	.49935	.19157	-.15894	.14474	10 145
	-.14293581		.34903317		.14231764	10 146
.40000	.37948	.51094	.18558	-.15387	.14412	10 147
	-.14293581		.34903317		.14262913	10 148
.60000	.37641	.52231	.17980	-.14880	.14349	10 149
	-.14293582		.34903318		.14294063	10 150
.80000	.37344	.53344	.17423	-.14374	.14287	10 151
	-.14293581		.34903316		.14325212	10 152
1.00000	.37058	.54432	.16886	-.13867	.14225	10 153
	-.14293582		.34903316		.14356361	10 154
1.20000	.36782	.55494	.16370	-.13360	.14162	10 155
	-.14293581		.34903317		.14387511	10 156
1.40000	.36517	.56528	.15874	-.12853	.14100	10 157
	-.14293582		.34903317		.14418660	10 158
1.60000	.36262	.57532	.15399	-.12346	.14038	10 159
	-.14293582		.34903317		.14449810	10 160
	.99984769					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	IO1MD	RCKP	PDIF	RCKK	PDIF	1°
.20000	-.00044	0.00000	.01666	.01656	1057.03940	1 161
.01703	1039.03470	-.00002	107.87202	.01656	-.00010	1 162
.40000	-.00045	0.00000	.01660	.01650	1057.03970	1 163
.01697	1039.09410	-.00002	108.08290	.01650	-.00010	1 164
.60000	-.00046	0.00000	.01655	.01645	1057.04010	1 165
.01692	1039.15360	-.00002	108.29500	.01645	-.00010	1 166
.80000	-.00048	0.00000	.01649	.01640	1057.04040	1 167

.01686	1039.21320	-.00002	108.50742	.01640	-.00010	1 168
1.00000	-.00049	0.00000	.01643	.01634	1057.04070	1 169
.01680	1039.27280	-.00002	108.72006	.01634	-.00011	1 170
1.20000	-.00050	0.00000	.01638	.01629	1057.04110	1 171
.01675	1039.33220	-.00002	108.93301	.01629	-.00011	1 172
1.40000	-.00051	0.00000	.01632	.01624	1057.04150	1 173
.01669	1039.39190	-.00002	109.14624	.01624	-.00011	1 174
1.60000	-.00053	0.00000	.01626	.01619	1057.04180	1 175
.01664	1039.45140	-.00002	109.35973	.01619	-.00011	1 176
	.98480775					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	I01MD	RCKP	PDIF	RCKK	PDIF	10°
.20000	-.01058	.10859	.02809	-.36586	.36936	2 177
.49585	.20474	.10866	.06685	-.36580	-.01482	2 178
.40000	-.01047	.10770	.02109	-.35970	.36876	2 179
.49886	.20322	.10774	.03131	-.35964	-.01488	2 180
.60000	-.01036	.10681	.01407	-.35349	.36818	2 181
.50184	.20172	.10680	-.00543	-.35343	-.01495	2 182
.80000	-.01026	.10590	.00702	-.34722	.36763	2 183
.50480	.20025	.10586	-.04340	-.34717	-.01501	2 184
1.00000	-.01015	.10499	-.00005	-.34091	.36711	2 185
.50774	.19880	.10490	-.08266	-.34086	-.01508	2 186
1.20000	-.01004	.10407	-.00716	-.33455	.36661	2 187
.51066	.19738	.10394	-.12325	-.33450	-.01514	2 188
1.40000	-.00994	.10313	-.01429	-.32814	.36615	2 189
.51356	.19599	.10296	-.16519	-.32809	-.01521	2 190
1.60000	-.00983	.10219	-.02144	-.32169	.36572	2 191
.51644	.19462	.10198	-.20853	-.32164	-.01528	2 192
	.93969262					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	I01MD	RCKP	PDIF	RCKK	PDIF	20°
.20000	-.03788	.40790	.25440	-.42368	.24538	3 193
-.03955	.39403	.41008	.53163	-.42326	-.09738	3 194
.40000	-.03681	.40357	.24307	-.41791	.23890	3 195
-.02078	.38030	.40579	.54865	-.41750	-.09791	3 196
.60000	-.03575	.39877	.23141	-.41180	.23271	3 197
-.00159	.36695	.40103	.56500	-.41140	-.09840	3 198
.80000	-.03468	.39349	.21940	-.40534	.22680	3 199
.01800	.35396	.39579	.58063	-.40494	-.09887	3 200

1.00000	-.03362	.38773	.20708	-.39853	.22117	3 201
.03797	.34135	.39006	.59546	-.39814	-.09928	3 202
1.20000	-.03255	.38147	.19445	-.39137	.21583	3 203
.05830	.32911	.38381	.60942	-.39098	-.09966	3 204
1.40000	-.03149	.37471	.18153	-.38386	.21077	3 205
.07894	.31724	.37706	.62244	-.38347	-.09999	3 206
1.60000	-.03042	.36744	.16833	-.37600	.20600	3 207
.09985	.30574	.36979	.63441	-.37562	-.10026	3 208

.86602540

S12	CX HX	CKP	CNN	CKK	PPPP	
D	IO1MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.06311	.63177	.56551	-.23050	.14828	4 209
-.03340	.41912	.62987	-.30206	-.22974	-.33316	4 210
.40000	-.06119	.62959	.56318	-.22356	.13747	4 211
-.01087	.39905	.62780	-.28571	-.22279	-.34334	4 212
.60000	-.05926	.62643	.56030	-.21620	.12718	4 213
.01256	.37964	.62474	-.27132	-.21544	-.35418	4 214
.80000	-.05734	.62223	.55683	-.20842	.11742	4 215
.03688	.36088	.62062	-.25909	-.20766	-.36577	4 216
1.00000	-.05542	.61690	.55273	-.20023	.10818	4 217
.06206	.34279	.61537	-.24923	-.19947	-.37821	4 218
1.20000	-.05349	.61040	.54799	-.19161	.09947	4 219
.08804	.32535	.60893	-.24200	-.19087	-.39164	4 220
1.40000	-.05157	.60267	.54256	-.18259	.09129	4 221
.11476	.30857	.60124	-.23769	-.18186	-.40620	4 222
1.60000	-.04965	.59364	.53644	-.17318	.08363	4 223
.14217	.29245	.59224	-.23661	-.17245	-.42210	4 224

.76604447

S12	CX HX	CKP	CNN	CKK	PPPP	
D	IO1MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.07133	.73716	.74320	-.11280	.02186	5 225
.19922	.31431	.73234	-.65784	-.11186	-.84580	5 226
.40000	-.07014	.73700	.74821	-.10667	.01549	5 227
.21184	.30433	.73231	-.64003	-.10572	-.89801	5 228
.60000	-.06895	.73627	.75279	-.10022	.00940	5 229
.22476	.29462	.73171	-.62422	-.09927	-.95862	5 230
.80000	-.06776	.73497	.75690	-.09345	.00359	5 231
.23795	.28518	.73051	-.61050	-.09250	-1.02994	5 232

1.00000	-.06657	.73305	.76052	-.08837	-.00192	5 233
.25140	.27602	.72869	-.59898	-.08541	-1.11524	5 234
1.20000	-.06538	.73051	.76362	-.07897	-.00715	5 235
.26509	.26713	.72622	-.58979	-.07802	-1.21926	5 236
1.40000	-.06419	.72731	.76616	-.07125	-.01210	5 237
.27899	.25850	.72309	-.58304	-.07031	-1.34917	5 238
1.60000	-.06300	.72344	.76812	-.06324	-.01677	5 239
.29308	.25015	.71928	-.57887	-.06229	-1.51628	5 240

.64278762

S12 D	CX HX IO1MD	CKP RCKP	CNN PDIF	CKK RCKK	PPPP PDIF	
.20000	-.06445	.72581	.82484	-.06565	-.08826	6 241
.47206	.19048	.72194	-.53578	-.06472	-1.44632	6 242
.40000	-.06521	.73203	.82793	-.06416	-.08715	6 243
.46423	.19390	.72825	-.51968	-.06322	-1.49909	6 244
.60000	-.06597	.73812	.83092	-.06254	-.08600	6 245
.45636	.19737	.73441	-.50442	-.06158	-1.55730	6 246
.80000	-.06674	.74406	.83381	-.06078	-.08479	6 247
.44845	.20091	.74043	-.48995	-.05981	-1.62173	6 248
1.00000	-.06750	.74986	.83659	-.05890	-.08354	6 249
.44049	.20451	.74630	-.47625	-.05792	-1.69335	6 250
1.20000	-.06826	.75551	.83926	-.05689	-.08223	6 251
.43251	.20817	.75202	-.46331	-.05589	-1.77330	6 252
1.40000	-.06903	.76102	.84183	-.05475	-.08087	6 253
.42449	.21189	.75760	-.45108	-.05375	-1.86301	6 254
1.60000	-.06979	.76638	.84430	-.05249	-.07947	6 255
.41644	.21568	.76303	-.43955	-.05147	-1.96427	6 256

.50000004

S12 D	CX HX IO1MD	CKP RCKP	CNN PDIF	CKK RCKK	PPPP PDIF	
.20000	-.05470	.64218	.79355	-.08690	-.14016	7 257
.61002	.13543	.64379	.24938	-.08603	-1.01332	7 258
.40000	-.05661	.65701	.79455	-.08912	-.13638	7 259
.59656	.14163	.65856	.23573	-.08823	-1.00747	7 260
.60000	-.05852	.67123	.79549	-.09138	-.13244	7 261
.58283	.14809	.67273	.22233	-.09048	-1.00024	7 262
.80000	-.06043	.68484	.79637	-.09371	-.12834	7 263
.56885	.15482	.68628	.20917	-.09279	-.99181	7 264
1.00000	-.06234	.69784	.79719	-.09608	-.12409	7 265

.55466	.16181	.69922	.19622	-.09514	-.98235	7 266
1.20000	-.06425	.71025	.79794	-.09849	-.11969	7 267
.54027	.16906	.71155	.18346	-.09754	-.97201	7 268
1.40000	-.06616	.72206	.79864	-.10095	-.11513	7 269
.52571	.17658	.72329	.17089	-.09999	-.96091	7 270
1.60000	-.06806	.73328	.79927	-.10344	-.11041	7 271
.51100	.18436	.73444	.15848	-.10246	-.94919	7 272
	.54202021					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	I01MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.05133	.58716	.68817	-.14310	-.13928	8 273
.58439	.14844	.59603	1.48795	-.14222	-.61633	8 274
.40000	-.05238	.59605	.68966	-.14809	-.13757	8 275
.58529	.14883	.60488	1.46011	-.14721	-.60016	8 276
.60000	-.05343	.60455	.69074	-.15292	-.13567	8 277
.58591	.14939	.61332	1.43018	-.15203	-.58488	8 278
.80000	-.05448	.61264	.69143	-.15757	-.13360	8 279
.58627	.15012	.62133	1.39826	-.15667	-.57038	8 280
1.00000	-.05552	.62033	.69171	-.16204	-.13134	8 281
.58636	.15103	.62891	1.36447	-.16115	-.55656	8 282
1.20000	-.05657	.62762	.69161	-.16634	-.12889	8 283
.58620	.15210	.63607	1.32891	-.16544	-.54336	8 284
1.40000	-.05762	.63448	.69113	-.17045	-.12626	8 285
.58579	.15334	.64279	1.29165	-.16955	-.53070	8 286
1.60000	-.05867	.64094	.69028	-.17438	-.12344	8 287
.58513	.15475	.64907	1.25279	-.17348	-.51853	8 288
	.17364828					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	I01MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.05364	.58507	.59737	-.19427	-.11826	9 289
.51582	.18135	.59963	2.42812	-.19342	-.43754	9 290
.40000	-.05280	.57863	.59615	-.19999	-.11987	9 291
.52970	.17540	.59328	2.46840	-.19914	-.42491	9 292
.60000	-.05196	.57196	.59471	-.20539	-.12137	9 293
.54356	.16954	.58668	2.50788	-.20454	-.41328	9 294
.80000	-.05113	.56507	.59306	-.21047	-.12276	9 295
.55738	.16380	.57984	2.54651	-.20962	-.40251	9 296
1.00000	-.05029	.55795	.59120	-.21521	-.12404	9 297
.57115	.15815	.57276	2.58426	-.21437	-.39252	9 298

1.20000	-.04946	.55062	.58912	-.21961	-.12520	9 299
.58485	.15262	.56544	2.62108	-.21878	-.38322	9 300
1.40000	-.04862	.54307	.58683	-.22367	-.12625	9 301
.59847	.14719	.55789	2.65694	-.22284	-.37453	9 302
1.60000	-.04778	.53531	.58433	-.22737	-.12718	9 303
.61201	.14186	.55012	2.69179	-.22654	-.36640	9 304

.01745244

S12 D	CX HX I01MD	CKP RCKP	CNN PDIF	CKK RCKK	PPPP PDIF	
.20000	-.05547	.59211	.56572	-.21687	-.10735	10 305
.49619	.19278	.60877	2.73617	-.21620	-.31018	10 306
.40000	-.05370	.57842	.56209	-.21924	-.11052	10 307
.50964	.18608	.59521	2.82194	-.21856	-.30896	10 308
.60000	-.05193	.56433	.55853	-.22155	-.11359	10 309
.52289	.17958	.58127	2.91324	-.22087	-.30779	10 310
.80000	-.05017	.54987	.55502	-.22381	-.11656	10 311
.53594	.17330	.56693	3.01062	-.22312	-.30666	10 312
1.00000	-.04840	.53502	.55158	-.22600	-.11942	10 313
.54876	.16721	.55222	3.11469	-.22531	-.30559	10 314
1.20000	-.04663	.51979	.54821	-.22812	-.12218	10 315
.56135	.16134	.53712	3.22620	-.22743	-.30457	10 316
1.40000	-.04486	.50419	.54491	-.23017	-.12483	10 317
.57369	.15567	.52164	3.34597	-.22948	-.30360	10 318
1.60000	-.04309	.48822	.54169	-.23215	-.12738	10 319
.58576	.15021	.50579	3.47494	-.23145	-.30268	10 320

POLARISATION

S12/DEG	1	10	20	30	40	50	60	70	80	89
.60000	-.00008	.14520	.31199	.37734	.39928	.38187	.31560	.21529	.10648	.01056
.80000	-.00008	.14547	.31750	.38789	.40622	.38092	.31160	.21316	.10613	.01056
1.00000	-.00008	.14573	.32293	.39842	.41305	.37993	.30756	.21094	.10575	.01055
1.20000	-.00008	.14599	.32827	.40890	.41976	.37889	.30349	.20864	.10533	.01054
1.40000	-.00008	.14623	.33350	.41927	.42633	.37781	.29939	.20627	.10488	.01053

312 MEV SCATTERING MATRIX %IM. PART¤

YA	YC	YM	YG	YH	
-2.62950	-.00055	-.00824	.07585	.08409	1
.33846	-.00541	-.00667	.07545	.08226	2
.32565	-.01002	-.00216	.07428	.07715	3
.28894	-.01348	.00458	.07231	.07000	4
.24231	-.01606	.01237	.06933	.06233	5
.19077	-.01836	.01968	.06484	.05550	6
.13741	-.02081	.02487	.05807	.05035	7
.08411	-.02331	.02659	.04822	.04704	8
.03215	-.02528	.02407	.03469	.04532	9
-.01245	-.02603	.01810	.01916	.04481	10

OPEP CENTRAL FORCE CHANGING IN L#5 PHASES
COULOMB INTERACTION NOT INCLUDED

	.99984769						
S12	IO	D	IO1MD	HX	XM		
	AX		CX		GX		
.20000	.47564	-.04833	.49863	-.04954	-.27941	1	1
	.14788967		.00971534		-.32754645	1	2
.40000	.47384	-.04198	.49373	-.04954	-.27754	1	3
	.15350865		.00971534		-.32567345	1	4
.60000	.47213	-.03545	.48887	-.04954	-.27567	1	5
	.15912765		.00971534		-.32380045	1	6
.80000	.47050	-.02875	.48403	-.04954	-.27379	1	7
	.16474665		.00971534		-.32192745	1	8
1.00000	.46896	-.02188	.47922	-.04954	-.27192	1	9
	.17036562		.00971534		-.32005445	1	10
1.20000	.46750	-.01484	.47444	-.04954	-.27005	1	11
	.17598462		.00971534		-.31818145	1	12
1.40000	.46612	-.00764	.46969	-.04954	-.26817	1	13
	.18160362		.00971534		-.31630845	1	14
1.60000	.46483	-.00027	.46496	-.04954	-.26630	1	15
	.18722260		.00971534		-.31443545	1	16

	.98480775						
S12	IO	D	IO1MD	HX	XM		
	AX		CX		GX		
.20000	.41451	.11039	.36875	-.10495	-.26584	2	17
	.14419672		.09561890		-.25835555	2	18
.40000	.41350	.11556	.36571	-.10495	-.26437	2	19
	.14861204		.09561890		-.25688377	2	20
.60000	.41255	.12083	.36270	-.10495	-.26290	2	21
	.15302735		.09561891		-.25541200	2	22
.80000	.41165	.12619	.35970	-.10495	-.26143	2	23
	.15744266		.09561891		-.25394025	2	24
1.00000	.41080	.13165	.35672	-.10495	-.25996	2	25
	.16185798		.09561891		-.25246847	2	26
1.20000	.41001	.13719	.35375	-.10495	-.25849	2	27
	.16627329		.09561890		-.25099670	2	28
1.40000	.40926	.14282	.35081	-.10495	-.25701	2	29

	.17068861		.09561890		-.24952493	2	30
1.60000	.40857	.14854	.34788	-.10495	-.25554	2	31
	.17510393		.09561890		-.24805316	2	32
	.93969262						
S12	IO	D	IO1MD	HX	XM		
	AX		CX		GX		
.20000	.37267	.28505	.26644	-.18306	-.22693	3	33
	.13065702		.18232263		-.14143595	3	34
.40000	.37255	.28637	.26586	-.18306	-.22642	3	35
	.13218602		.18232263		-.14092629	3	36
.60000	.37244	.28770	.26529	-.18306	-.22591	3	37
	.13371503		.18232263		-.14041662	3	38
.80000	.37234	.28903	.26472	-.18306	-.22540	3	39
	.13524401		.18232263		-.13990695	3	40
1.00000	.37224	.29037	.26415	-.18306	-.22489	3	41
	.13677302		.18232263		-.13939729	3	42
1.20000	.37215	.29172	.26358	-.18306	-.22438	3	43
	.13830203		.18232263		-.13888762	3	44
1.40000	.37206	.29308	.26302	-.18306	-.22388	3	45
	.13983101		.18232263		-.13837795	3	46
1.60000	.37198	.29444	.26245	-.18306	-.22337	3	47
	.14136002		.18232263		-.13786829	3	48
	.86602540						
S12	IO	D	IO1MD	HX	XM		
	AX		CX		GX		
.20000	.37193	.34109	.24506	-.21769	-.16888	4	49
	.10246802		.25297639		-.05073894	4	50
.40000	.37190	.34058	.24523	-.21769	-.16930	4	51
	.10121059		.25297639		-.05115808	4	52
.60000	.37188	.34008	.24541	-.21769	-.16972	4	53
	.09995317		.25297640		-.05157723	4	54
.80000	.37185	.33957	.24558	-.21769	-.17014	4	55
	.09869573		.25297640		-.05199637	4	56
1.00000	.37184	.33907	.24575	-.21769	-.17056	4	57
	.09743829		.25297640		-.05241552	4	58
1.20000	.37183	.33858	.24593	-.21769	-.17098	4	59
	.09618085		.25297639		-.05283466	4	60
1.40000	.37182	.33808	.24611	-.21769	-.17140	4	61
	.09492341		.25297639		-.05325381	4	62
1.60000	.37181	.33760	.24629	-.21769	-.17182	4	63
	.09366599		.25297639		-.05367296	4	64
	.76604447						
S12	IO	D	IO1MD	HX	XM		
	AX		CX		GX		
.20000	.37083	.38440	.22827	-.21786	-.10013	5	65
	.05734616		.30361942		.01343439	5	66
.40000	.37068	.38438	.22819	-.21786	-.10092	5	67
	.05498259		.30361942		.01264653	5	68
.60000	.37054	.38437	.22812	-.21786	-.10170	5	69
	.05261899		.30361942		.01185867	5	70
.80000	.37043	.38436	.22804	-.21786	-.10249	5	71
	.05025542		.30361942		.01107081	5	72
1.00000	.37032	.38437	.22798	-.21786	-.10328	5	73
	.04789182		.30361942		.01028295	5	74
1.20000	.37023	.38440	.22791	-.21786	-.10407	5	75

	.04592824		.30361942		.00949508	5	76
1.40000	.37016	.38443	.22786	-.21786	-.10486	5	77
	.04316464		.30361942		.00870722	5	78
1.60000	.37010	.38447	.22780	-.21786	-.10564	5	79
	.04080107		.30361942		.00791936	5	80
	.64278762						
S12	IO	D	IO1MD	HX	XM		
	AX		CX		GX		
.20000	.36514	.43566	.20606	-.20064	-.02965	6	81
	-.00036222		.33413558		.05992729	6	82
.40000	.36506	.43616	.20583	-.20064	-.03013	6	83
	-.00179546		.33413558		.05944954	6	84
.60000	.36498	.43666	.20560	-.20064	-.03061	6	85
	-.00322868		.33413558		.05897180	6	86
.80000	.36491	.43716	.20538	-.20064	-.03109	6	87
	-.00466193		.33413558		.05849405	6	88
1.00000	.36484	.43767	.20516	-.20064	-.03156	6	89
	-.00609517		.33413558		.05801630	6	90
1.20000	.36478	.43818	.20494	-.20064	-.03204	6	91
	-.00752842		.33413558		.05753855	6	92
1.40000	.36473	.43870	.20472	-.20064	-.03252	6	93
	-.00896166		.33413558		.05706081	6	94
1.60000	.36468	.43922	.20450	-.20064	-.03300	6	95
	-.01039490		.33413558		.05658306	6	96
	.50000004						
S12	IO	D	IO1MD	HX	XM		
	AX		CX		GX		
.20000	.36146	.48414	.18646	-.17777	.03456	7	97
	-.05973962		.34798623		.09453606	7	98
.40000	.36148	.48381	.18659	-.17777	.03473	7	99
	-.05923365		.34798623		.09470471	7	100
.60000	.36149	.48347	.18672	-.17777	.03490	7	101
	-.05872766		.34798623		.09487338	7	102
.80000	.36151	.48314	.18684	-.17777	.03507	7	103
	-.05822167		.34798623		.09504204	7	104
1.00000	.36153	.48281	.18697	-.17777	.03524	7	105
	-.05771569		.34798623		.09521070	7	106
1.20000	.36155	.48248	.18710	-.17777	.03540	7	107
	-.05720970		.34798623		.09537936	7	108
1.40000	.36156	.48215	.18723	-.17777	.03557	7	109
	-.05670371		.34798623		.09554803	7	110
1.60000	.36158	.48183	.18736	-.17777	.03574	7	111
	-.05619773		.34798623		.09571669	7	112
	.34202021						
S12	IO	D	IO1MD	HX	XM		
	AX		CX		GX		
.20000	.36272	.51844	.17466	-.15683	.08654	8	113
	-.10777799		.35100803		.12022219	8	114
.40000	.36272	.51682	.17526	-.15683	.08715	8	115
	-.10593037		.35100803		.12083807	8	116
.60000	.36274	.51520	.17585	-.15683	.08777	8	117
	-.10408274		.35100803		.12145394	8	118
.80000	.36277	.51358	.17645	-.15683	.08838	8	119
	-.10223511		.35100803		.12206982	8	120
1.00000	.36281	.51197	.17706	-.15683	.08900	8	121

	-.10038749		.35100803		.12268569	8 122
1.20000	.36285	.51036	.17766	-.15683	.08961	8 123
	-.09853986		.35100803		.12330157	8 124
1.40000	.36291	.50875	.17827	-.15683	.09023	8 125
	-.09669223		.35100803		.12391744	8 126
1.60000	.36297	.50715	.17888	-.15683	.09085	8 127
	-.09484461		.35100803		.12453332	8 128
	.17364828					
S12	IO	D	IO1MD	HX	XM	
	AX		CX		GX	
.20000	.36629	.53707	.16956	-.14254	.12258	9 129
	-.13543572		.34954924		.13685804	9 130
.40000	.36629	.53548	.17014	-.14254	.12311	9 131
	-.13385307		.34954924		.13738559	9 132
.60000	.36629	.53390	.17072	-.14254	.12363	9 133
	-.13227042		.34954924		.13791314	9 134
.80000	.36629	.53231	.17131	-.14254	.12416	9 135
	-.13068777		.34954924		.13844069	9 136
1.00000	.36631	.53073	.17189	-.14254	.12469	9 137
	-.12910512		.34954924		.13896824	9 138
1.20000	.36632	.52915	.17248	-.14254	.12522	9 139
	-.12752247		.34954924		.13949579	9 140
1.40000	.36635	.52757	.17307	-.14254	.12574	9 141
	-.12593982		.34954924		.14002334	9 142
1.60000	.36638	.52600	.17366	-.14254	.12627	9 143
	-.12435717		.34954924		.14055089	9 144
	.01745244					
S12	IO	D	IO1MD	HX	XM	
	AX		CX		GX	
.20000	.36806	.54923	.16590	-.13755	.14019	10 145
	-.14157036		.34847232		.14152401	10 146
.40000	.36806	.54905	.16597	-.13755	.14025	10 147
	-.14138633		.34847232		.14158535	10 148
.60000	.36806	.54886	.16604	-.13755	.14031	10 149
	-.14120230		.34847232		.14164669	10 150
.80000	.36806	.54867	.16611	-.13755	.14037	10 151
	-.14101827		.34847232		.14170804	10 152
1.00000	.36806	.54848	.16618	-.13755	.14043	10 153
	-.14083424		.34847232		.14176938	10 154
1.20000	.36806	.54829	.16625	-.13755	.14050	10 155
	-.14065021		.34847232		.14183072	10 156
1.40000	.36806	.54810	.16632	-.13755	.14056	10 157
	-.14046618		.34847232		.14189207	10 158
1.60000	.36806	.54791	.16639	-.13755	.14062	10 159
	-.14028215		.34847232		.14195341	10 160
	.99984769					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	IO1MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.00048	.00456	-.61604	-.61781	.47526	1 161
.26197	.35103	.00519	12.08675	-.61781	-.00011	1 162
.40000	-.00048	.00458	-.61863	-.62036	.47346	1 162
.25238	.35425	.00521	12.12535	-.62036	-.00011	1 164
.60000	-.00048	.00460	-.62106	-.62276	.47175	1 165

.24280	.35749	.00523	12.16258	-.62275	-.00011	1 166
.80000	-.00048	.00461	-.62334	-.62500	.47012	1 167
.23323	.36076	.00525	12.19844	-.62500	-.00011	1 168
1.00000	-.00048	.00463	-.62547	-.62708	.46858	1 169
.22367	.36406	.00527	12.23294	-.62708	-.00011	1 170
1.20000	-.00048	.00464	-.62743	-.62901	.46712	1 171
.21412	.36739	.00529	12.26607	-.62901	-.00011	1 172
1.40000	-.00048	.00466	-.62924	-.63077	.46574	1 173
.20461	.37075	.00531	12.29784	-.63077	-.00011	1 174
1.60000	-.00048	.00467	-.63088	-.63237	.46445	1 175
.19512	.37413	.00533	12.32825	-.63237	-.00011	1 176
	.98480775					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	IO1MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.01003	.10254	-.41034	-.57436	.37774	2 177
.12486	.36275	.10758	4.69131	-.57428	-.01479	2 178
.40000	-.01003	.10278	-.41229	-.57351	.37674	2 179
.11687	.36517	.10785	4.69870	-.57342	-.01487	2 180
.60000	-.01003	.10302	-.41415	-.57254	.37579	2 181
.10892	.36761	.10811	4.70559	-.57245	-.01493	2 182
.80000	-.01003	.10325	-.41593	-.57144	.37489	2 183
.10100	.37007	.10835	4.71198	-.57136	-.01501	2 184
1.00000	-.01003	.10346	-.41762	-.57023	.37404	2 185
.09312	.37254	.10858	4.71787	-.57015	-.01508	2 186
1.20000	-.01003	.10366	-.41922	-.56896	.37324	2 187
.08528	.37504	.10880	4.72328	-.56881	-.01515	2 188
1.40000	-.01003	.10385	-.42073	-.56745	.37250	2 189
.07749	.37755	.10900	4.72818	-.56736	-.01523	2 190
1.60000	-.01003	.10403	-.42216	-.56588	.37181	2 191
.06974	.38007	.10919	4.73259	-.56579	-.01530	2 192
	.93969262					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	IO1MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.03337	.36939	.09578	-.36655	.23904	3 193
-.04784	.39056	.37307	.98845	-.36615	-.10839	3 194
.40000	-.03337	.36950	.09508	-.36445	.23892	3 195
-.05013	.39123	.37318	.98650	-.36406	-.10902	3 196
.60000	-.03337	.36961	.09438	-.36234	.23881	3 197
-.05241	.39196	.37329	.98450	-.36195	-.10968	3 198

.80000	-.03337	.36972	.09369	-.36022	.23871	3 199
-.05468	.39270	.37338	.98247	-.35983	-.11032	3 200
1.00000	-.03337	.36981	.09300	-.35809	.23861	3 201
-.05693	.39344	.37348	.98041	-.35769	-.11100	3 202
1.20000	-.03337	.36991	.09232	-.35594	.23852	3 203
-.05918	.39417	.37356	.97829	-.35554	-.11167	3 204
1.40000	-.03337	.36999	.09164	-.35378	.23843	3 205
-.06141	.39491	.37364	.97615	-.35339	-.11236	3 206
1.60000	-.03337	.37007	.09096	-.35161	.23835	3 207
-.06364	.39566	.37371	.97396	-.35121	-.11304	3 208

.86602540

S12	CX HX	CKP	CNN	CKK	PPPP	
D	IO1MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.05507	.60615	.50204	-.15186	.11470	4 209
.02627	.36216	.60480	-.22213	-.15112	-.49339	4 210
.40000	-.05507	.60619	.50276	-.15422	.11467	4 211
.02742	.36170	.60487	-.21929	-.15347	-.48604	4 212
.60000	-.05507	.60623	.50348	-.15657	.11465	4 213
.02857	.36125	.60492	-.21646	-.15582	-.47893	4 214
.80000	-.05507	.60627	.50420	-.15892	.11463	4 215
.02973	.36080	.60497	-.21367	-.15817	-.47203	4 216
1.00000	-.05507	.60629	.50492	-.16126	.11461	4 217
.03090	.36035	.60502	-.21090	-.16051	-.46535	4 218
1.20000	-.05507	.60631	.50564	-.16359	.11460	4 219
.03207	.35990	.60505	-.20815	-.16284	-.45885	4 220
1.40000	-.05507	.60633	.50635	-.16592	.11459	4 221
.03325	.35945	.60508	-.20543	-.16517	-.45256	4 222
1.60000	-.05507	.60633	.50706	-.16824	.11459	4 223
.03444	.35901	.60510	-.20273	-.16749	-.44645	4 224

.76604447

S12	CX HX	CKP	CNN	CKK	PPPP	
D	IO1MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.06614	.72852	.73655	-.04064	.00028	5 225
.23586	.28336	.72381	-.64991	-.03976	-2.36515	5 226
.40000	-.06614	.72881	.73799	-.04514	.00013	5 227
.23689	.28286	.72415	-.64382	-.04419	-2.12755	5 228
.60000	-.06614	.72907	.73943	-.04962	0.00000	5 229
.23794	.28238	.72445	-.63783	-.04868	-1.93418	5 230

.80000	-.06614	.72930	.74085	-.05409	-.00011	5 231
.23900	.28189	.72473	-.63192	-.05315	-1.77375	5 232
1.00000	-.06614	.72951	.74223	-.05856	-.00022	5 233
.24008	.28141	.72497	-.62612	-.05761	-1.63849	5 234
1.20000	-.06614	.72968	.74363	-.06300	-.00030	5 235
.24118	.28094	.72518	-.62040	-.06206	-1.52291	5 236
1.40000	-.06614	.72983	.74501	-.06744	-.00038	5 237
.24229	.28047	.72537	-.61478	-.06649	-1.42299	5 238
1.60000	-.06614	.72994	.74636	-.07185	-.00044	5 239
.24343	.28001	.72552	-.60925	-.07091	-1.33577	5 240

	.64278762					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	IO1MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.06704	.75002	.83120	-.02933	-.08382	6 241
.43874	.20493	.74599	-.53980	-.02836	-3.41256	6 242
.40000	-.06704	.75019	.83193	-.03183	-.08390	6 243
.43876	.20488	.74619	-.53632	-.03086	-3.13967	6 244
.60000	-.06704	.75035	.83266	-.03432	-.08398	6 245
.43879	.20483	.74637	-.53287	-.03335	-2.90709	6 246
.80000	-.06704	.75049	.83339	-.03680	-.08405	6 247
.43882	.20478	.74654	-.52946	-.03583	-2.70859	6 248
1.00000	-.06704	.75063	.83410	-.03928	-.08412	6 249
.43885	.20473	.74670	-.52609	-.03831	-2.53539	6 250
1.20000	-.06704	.75075	.83481	-.04176	-.08418	6 251
.43889	.20468	.74685	-.52276	-.04079	-2.38346	6 252
1.40000	-.06704	.75087	.83551	-.04423	-.08423	6 253
.43893	.20463	.74699	-.51948	-.04326	-2.24922	6 254
1.60000	-.06704	.75097	.83621	-.04670	-.08428	6 255
.43898	.20459	.74711	-.51623	-.04573	-2.12948	6 256

	.50000004					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	IO1MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.06186	.70074	.80369	-.08533	-.12592	7 257
.55749	.15995	.70169	.13568	-.08440	-1.09538	7 258
.40000	-.06186	.70071	.80352	-.08457	-.12590	7 259
.55768	.15988	.70165	.13472	-.08365	-1.10499	7 260
.60000	-.06186	.70068	.80335	-.08381	-.12589	7 261
.55787	.15982	.70162	.13375	-.08289	-1.11479	7 262
.80000	-.06186	.70064	.80318	-.08306	-.12587	7 263

.55807	.15976	.70158	.13278	-.08213	-1.12477	7 264
1.00000	-.06186	.70061	.50301	-.08230	-.12585	7 265
.55826	.15969	.70154	.13180	-.08138	-1.13494	7 266
1.20000	-.06186	.70058	.80284	-.08154	-.12583	7 267
.55846	.15963	.70149	.13081	-.08062	-1.14531	7 268
1.40000	-.06186	.70054	.80266	-.08078	-.12582	7 269
.55866	.15957	.70145	.12982	-.07986	-1.15589	7 270
1.60000	-.06186	.70050	.80249	-.08002	-.12580	7 271
.55885	.15951	.70141	.12883	-.07910	-1.16667	7 272
	.34202021					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	I01MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.05505	.62375	.70233	-.16169	-.13378	8 273
.58665	.14992	.63195	1.29735	-.16080	-.55106	8 274
.40000	-.05505	.62373	.70202	-.15939	-.13377	8 275
.58798	.14944	.63192	1.29523	-.15851	-.55876	8 276
.60000	-.05505	.62370	.70170	-.15709	-.13375	8 277
.58931	.14897	.63187	1.29300	-.15620	-.56670	8 278
.80000	-.05505	.62366	.70136	-.15477	-.13372	8 279
.59064	.14850	.63181	1.29069	-.15388	-.57489	8 280
1.00000	-.05505	.62359	.70102	-.15244	-.13369	8 281
.59197	.14803	.63173	1.28828	-.15155	-.58335	8 282
1.20000	-.05505	.62351	.70067	-.15009	-.13364	8 283
.59330	.14757	.63164	1.28577	-.14921	-.59211	8 284
1.40000	-.05505	.62342	.70031	-.14774	-.13359	8 285
.59464	.14710	.63152	1.28317	-.14686	-.60114	8 286
1.60000	-.05505	.62331	.69994	-.14537	-.13352	8 287
.59597	.14665	.63140	1.28048	-.14449	-.61049	8 288
	.17364828					
S12	CX HX	CKP	CNN	CKK	PPPP	
D	I01MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.04982	.56114	.60192	-.21516	-.12666	9 289
.57067	.15726	.57555	2.50354	-.21433	-.38636	9 290
.40000	-.04982	.56115	.60181	-.21347	-.12667	9 291
.57215	.15671	.57556	2.50278	-.21265	-.38937	9 292
.60000	-.04982	.56116	.60170	-.21178	-.12667	9 293
.57362	.15617	.57556	2.50195	-.21095	-.39242	9 294
.80000	-.04982	.56115	.60159	-.21007	-.12666	9 295
.57510	.15563	.57554	2.50103	-.20924	-.39554	9 296

1.00000	-.04982	.56113	.60147	-.20836	-.12665	9 297
.57658	.15510	.57551	2.50004	-.20753	-.39870	9 298
1.20000	-.04982	.56110	.60134	-.20663	-.12663	9 299
.57806	.15456	.57548	2.49897	-.20580	-.40192	9 300
1.40000	-.04982	.56106	.60122	-.20489	-.12660	9 301
.57955	.15403	.57543	2.49782	-.20407	-.40520	9 302
1.60000	-.04982	.56101	.60108	-.20315	-.12657	9 303
.58103	.15350	.57537	2.49660	-.20232	-.40853	9 304

.01745244

S12	CX HX	CKP	CNN	CKK	PPPP	
D	I01MD	RCKP	PDIF	RCKK	PDIF	
.20000	-.04793	.53810	.56198	-.22140	-.12210	10 305
.55243	.16473	.55491	3.02770	-.22073	-.30505	10 306
.40000	-.04793	.53810	.56198	-.22122	-.12210	10 307
.55262	.16466	.55491	3.02769	-.22055	-.30531	10 308
.60000	-.04793	.53810	.56198	-.22104	-.12210	10 309
.55281	.16459	.55491	3.02768	-.22036	-.30556	10 310
.80000	-.04793	.53810	.56198	-.22085	-.12210	10 311
.55300	.16452	.55491	3.02767	-.22018	-.30582	10 312
1.00000	-.04793	.53810	.56198	-.22067	-.12210	10 313
.55318	.16445	.55491	3.02766	-.21999	-.30607	10 314
1.20000	-.04793	.53810	.56197	-.22048	-.12210	10 315
.55337	.16438	.55490	3.02764	-.21981	-.30633	10 316
1.40000	-.04793	.53810	.56197	-.22030	-.12210	10 317
.55356	.16431	.55490	3.02763	-.21962	-.30658	10 318
1.60000	-.04793	.53810	.56197	-.22011	-.12210	10 319
.55375	.16424	.55490	3.02762	-.21944	-.30684	10 320

FIG. 6

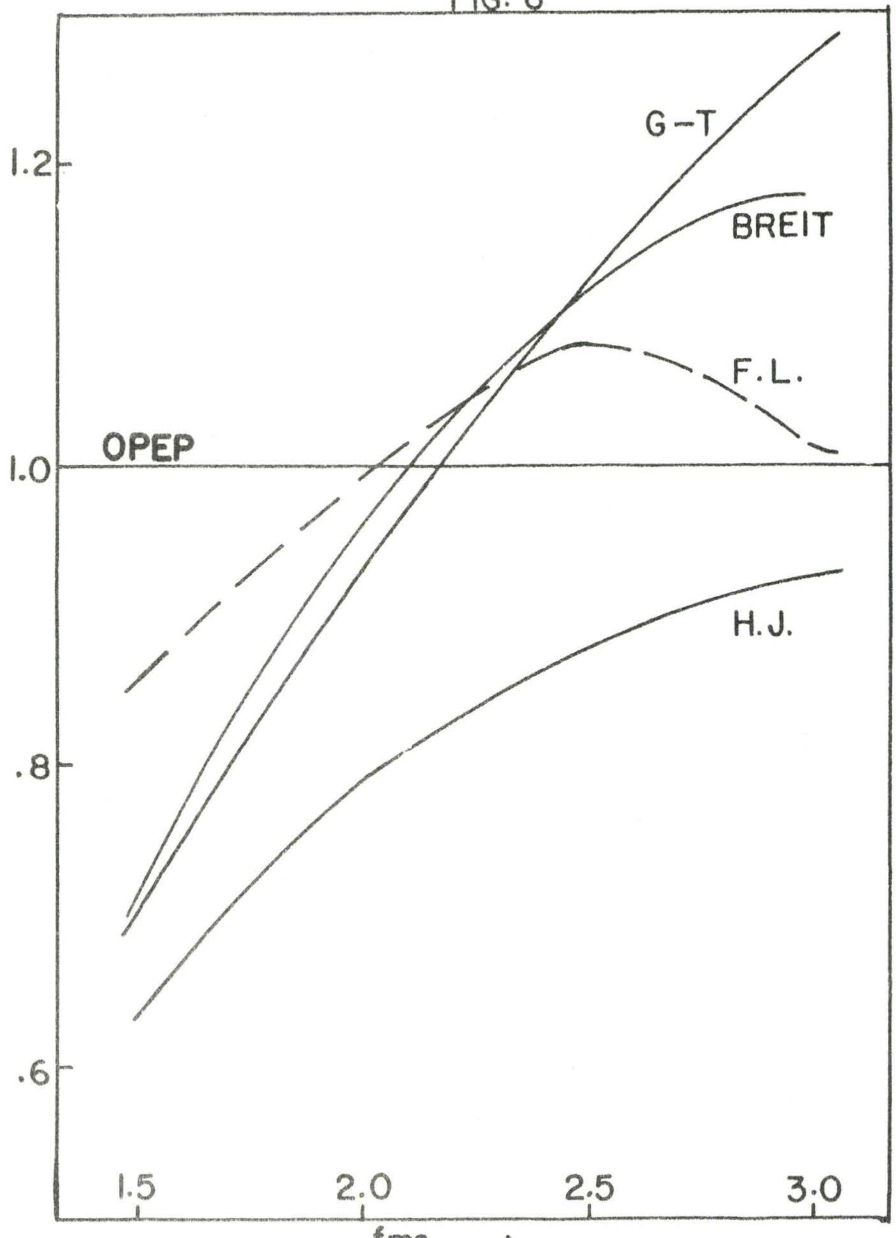


FIGURE 6: Strength of the tensor force in the p-p Gammel-Thaler (13), Breit (28), Feshbach-Lomon (26), and Hamada-Johnston (27) potentials as compared to the OPEP.

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