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A SEPARABLE APPROXIMATION OF THE NN-PARIS-POTENTIAL IN THE FRAMEWORK OF THE BETHE-SALPETER EQUATION

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Abstract

The Bethe-Salpeter equation is solved with a separable kernel for the most important nucleon-nucleon partial wave states. We employ the Ernst Shakin-Thaler method in the framework of minimal relativity (Blankenbeckler-Sugar equation) to generate a separable representation of the meson-theoretical Paris potential. These separable interactions, which closely approximate the on-shell- and half-off-shell behaviour of the Paris potential, are then cast into a covariant form for application in the Bethe-Salpeter equation. The role of relativistic effects is discussed with respect to on-shell and off-shell properties of the NN-system.

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I. Introduction

During the last decade interest has focused around covariant two body equations with regard to relativistic three body calculations. Due to the complexity of three body calculations, up till now nobody has used the four dimensional analogon of the Lippmann-Schwinger equation namely the Bethe-Salpeter (BS) equation for the description of the two particle subsystems. All "relativistic" calculations in three body problems have been performed within the framework of three dimensional reductions of the four dimensional Bethe-Salpeter (BS) equation.
Two particle equations of that type, which are widely used, are the so called Blankenbeckler-Sugar (BBS) equation (1), Gross equation (2), Erkelenz-Holinde equation (3) and Kadishevsky equation (4).
We have already shown in our previous works (5) that a reasonable description of NN and πN scattering can be performed in the framework of the BS-equation. We have been able to reproduce NN and πN scattering data without introducing some reduction techniques to go from four to three dimensions.
In all of these calculations the free parameters of the four dimensional Yamaguchi-type form factors were fitted in order to reproduce corresponding two body phase shifts as well as possible. However, no attention at all was paid to the off-shell behaviour of the two body T matrices.

Since it is well known that important features of three body systems (in the binding as well as in the scattering domain) are very sensitive to the underlying two body off-shell behaviour (6), it is our goal in this paper to present a separable four dimensional approach to the BS-equation, which yields reasonable descriptions of the on-shell as well as off-shell properties of the two nucleon system. Due to the fact that direct information on the off-shell behaviour is scarce and unsufficient for our purpose, we have chosen to regard the off-shell behaviour of a meson theoretical potential as basis for our calculations. Actually we took the Paris potential (7) as a reference model and followed a method which was given by ERNST, SHAKIN and THALER (EST)(7).

The EST-method ist established in three dimensions only; we have therefore divided our investigations into two steps. Firstly we construct a three dimensional separable potential (in the framework of the BBS equation), which reproduces the on- and half-off shell properties of the Paris potential (see Sec.III) satisfactorily. As a second step, we construct a four dimensional version of the obtained potential, by fixing the parameter ß and varying the coupling strengths within the BS-framework to refit the phase shift. We have seen that this second step has almost no influence on the off-shell behaviour.

In Sec.II we briefly introduce the BS-equation in its separable form.
Sec.III shows the results obtained with the EST-method in the NN system; in Sec.IV some concluding remarks will be given.

II. The BS Equation with Separable Interactions

The BS-equation

$$T(q,q';s) = V(q,q') + \frac{i}{4\pi^3} \int d^4k \quad V(q,k)G(k,s)T(k,q';s) \qquad (2.1)$$

describes the relativistic two particle scattering in terms of the T-matrix, of an interaction V, the kernel of the integral equation and the free two particle Green's function G. Since the total angular momentum is conserved, we may decompose T and V into partial wave components obtaining the partial wave decomposed BS-equation in momentum space

$$T_\ell(q_0,q,q_0',q';s) = V_\ell(q_0,q,q_0',q') + \frac{i}{4\pi^3} \int_{-\infty}^{+\infty} dk_0 \int_0^\infty k^2 dk \, . \, V_\ell(q_0,q,k_0,k)$$
$$G(k_0,k;s)T_\ell(k_0,k,q_0',q';s) \qquad (2.2)$$

with

$$G(k_0,k;s) = \{(k_0+a\sqrt{s})^2 - E_1^2 + i\varepsilon\}^{-1}\{(k_0-b\sqrt{s})^2 - E_2^2 + i\varepsilon\}^{-1}. \qquad (2.3)$$

Using the abbriviations $a = m_1/(m_1 + m_2)$ and $b = m_2/(m_1 + m_2)$; the relative momenta are given by

$q = (q_0,q) = aq_2 - bq_1;$

m_1 and m_2 are the masses of the particles with momenta q_1 and q_2.

q,k and q' are the initial, intermediate and final relative momenta, s the total energy squared in the center of mass system and $E_i = (k^2+m_i^2)^{\frac{1}{2}}$; $i=1,2$.

The phase shift is connected to the fully on-shell T-matrix by

$$T_\ell(p_0,p,p_0,p;s) = -\frac{8\pi\sqrt{s}}{p}\; e^{i\delta_\ell(p)}\sin\delta_\ell(p).$$

For the interaction V_ℓ we have chosen the following four dimensional separable ansatz (to simplify the discussion we show the formulae just for a rank one separable potential)

$$V_\ell(q_0,q,k_0,k)=v_\ell(q_0,q)\lambda_\ell v_\ell(k_0,k), \tag{2.4}$$

where λ_ℓ is the coupling parameter and $v_\ell(q_0,q)$ a relativistic generalization of the Yamaguchi form factor (vertex function)

$$v_\ell(q_0,q) = \frac{q^\ell}{(-q_0^2+q^2+\beta^2)^{\ell+1}}. \tag{2.5}$$

We have used "magic vectores" for a covariant treatment of the threshold behaviour (9). As a consequence the BS-equation can then be solved in closed form to give

$$T_\ell(q_0,q,q_0',q')=v_\ell(q_0,q)v_\ell(q_0',q')/D_\ell(s) \tag{2.6}$$

$$D_\ell(s) = \lambda_\ell^{-1} - \frac{i}{4\pi^3}\int_{-\infty}^{\infty} dk_0 \int_0^{\infty} k^2 dk\, v_\ell^2(k_0,k)G(k_0,k;s). \tag{2.7}$$

For the k_0-integration in the complex energy-plane in Eg. (2.7), we have to investigate the four singularities of the Green's function at momenta k_0

lower k_0-plane: upper k_0-plane:

$k_{01} = -a\sqrt{s}+E_1-i\varepsilon$ $\qquad$ $k_{02} = -a\sqrt{s}-E_1+i\varepsilon$

$k_{03} = b\sqrt{s}+E_2-i\varepsilon$ $\qquad$ $k_{04} = b\sqrt{s}-E_2+i\varepsilon$

with

$E_1 = \sqrt{k^2+m_1^2}$ and $E_2 = \sqrt{k^2+m_2^2}$, and in addition the singularities of the potential

$k_{05} = \sqrt{k^2+\beta^2}-i\varepsilon$ lower k_0-plane

$k_{06} = \sqrt{k^2+\beta^2}+i\varepsilon$ upper k_0-plane.

These potential poles are of second order for S waves and of fourth order for P and D waves.

Closing the contour in the lower plane, we are able to perform the k_0-integration as the sum of four residues; the second integral in Eq. (2.7) is solved numerically. By fitting the free parameters λ and β to the phase-shifts, one has to be careful, since the values of the variable β are constrained to avoid integration singularities. On the one hand β has to be less than two times the nucleon mass. In addition there exists a lower limit for β which depends on the scattering energy. For example for an energy range up to 350 MeV the lower bound $\beta \simeq \frac{1}{10}\ m^2$ for NN scattering.

III. NN scattering phase shifts and half-off-shell functions

The EST mechanism leads to the construction of a separable potential that reproduces the on- as well as off-shell behaviour of some arbitrary potential - in our case the Paris potential (9). One selects some energy points (interpolation points) in a particular channel (the number of energy points determines the rank of the constructed separable potentials) and the EST-method guarantees that the T-matrix of the Paris potential and the T-matrix of the separable potential approximation are identical at the chosen energy point (10).

It is well known that within a covariant three dimensional equation the parameters of the potential are close to the ones obtained from a fully relativistic four dimensional calculation. Therefore it is obvious to use such a semi-relativistic equation to handle the EST method. Suggesting that the resulting parameters of the separable potential lead to smaller corrections in the Bethe-Salpeter equation as it would be in the framework of the LS-equation.

As mentioned in Sec.I we use the BBS-equation as a starting point of our investigations, since in comparison to other three dimensional relativistic equations, the BBS-equation is a symmetric reduction of the BS-equation.

As a consequence, the creation of a four dimensional interaction is much easier to perform as by using an unsymmetric reduction of the BS-equation.

To show the accuracy of this method we have calculated the NN $^1S_0$, $^3S_1$-$^3D_1$, $^1P_1$, $^3P_0$ and $^3P_1$ phase shifts and the corresponding half-off-shell functions.

For the $^1S_0$ n-p wave we have used a rank-3 potential; in terms of the EST-method this corresponds to three interpolation energies $E_1 = 0$, $E_2 = 100$ and $E_3 = 500$ MeV.

The appropriate separable interaction ( ) where each vertex function consists of the sum of five terms, is given by

$$V_0(q_0,q,k_0,k) = \sum_{i=1}^{3} v_i(q_0,q)\ \lambda_i v_i(k_0,k) \tag{3.1}$$

$$v_i(q_0,q) = \sum_{j=1}^{5} \frac{C_{ij}}{(-q_0^2+q^2+\beta_j^2)} . \tag{3.2}$$

The parameters of the potential are given in table 1; in fig. 1 we show the n-p $^1S_0$ scattering phase shift obtained within the BS-equation, whereby we show the phase shifts, obtained without and with a change of the coupling strengths. In addition the $^1S_0$ phase within the BBS-equation is presented. To show the quality of our calculation we compare in fig. 1 our results also with the $^1S_0$ phase shift of the Paris potential and with the phenomenological data of ARNDT et al. (11).

In order to use the BS-equation instead of the BBS-equation, we had to refit the coupling strengths λ_1, λ_2 and λ_3. All other parameters we could keep fixed since the phase shifts are not as sensitive on them as on the coupling strengths. We had to rise λ_1 and λ_2 to get more attraction and to lower λ_3, which is responsible for the repulsion, to get less repulsion (see table 1); this is also evident if you look at the dashed-point line in fig. 1.

Fig. 2 shows the half-off-shell function

$$f(q_0,q,s) = \frac{T(q_0,q,p_0,p;s)}{T(p_0,p,p_0,p,s)} \qquad (3.3)$$

at the energy E_{lab} = 100 MeV. As can be seen from fig. 2, good agreement of the BS-description of the $^1S_0$ partial wave with the sorresponding property of the Paris potential is obtained. The results of half-off-shell functions at the two additional interpolation energies (E = 0 MeV, E = 500 MeV) are of the same accuracy as compared in fig. 2; they are still reasonable at the whole energy domain.

For the $^1P_1$, $^3P_0$, $^3P_1$ channel we have constructed a rank-2 separable potential (each vertex function consists again of five terms)

$$V_1\ (q_0,q,k_0,k) = \sum_{i=1}^{2} v_i(q_0,q)\ \lambda_i v_i(k_0.k) \qquad (3.4)$$

$$v_i\ (q_0,q) = \sum_{j=1}^{5} \frac{C_{ij}\cdot q}{(-q_0^2+q^2+\beta_j^2)^2} \qquad (3.5)$$

Table 2 gives the potential parameters, the corresponding phase shifts are shown in figs. 3 - 5.

For the $^1P_1$ and $^3P_1$ state the interpolation energies were chosen at E_1 = 50 and E_2 = 150 MeV.

To obtain a good fit to the phase shifts in the framework of the BS-equation, both coupling strengths λ_1 and λ_2 had to be lowered by small amount (for both cases, see table 2). The half-off-shell behaviour, however, is in a good approximation to the corresponding Paris potential properties (fig. 6 and fig. 8); the reproduction is especially accurate at the interpolation energies .

A similar behaviour is found for the $^3P_0$ wave (interpolation energies: E_1: 50 MeV, E_2: 350 MeV): agreement with the NN-Paris potential is satisfactory. The absolute value of the coupling strength λ_1 (λ_1 is responsible for the attraction) had to be raised by a very small amount. In contradiction to λ_1, the coupling parameter λ_2, which is responsible for the repulsion in this partial wave had to be lowered to obtain satisfactory results in comparison to the experimental data (see table 2). The changes of the coupling parameters are obvious by looking at fig. 4, where the dashed-dotted line shows less attraction and to much repulsion. The relatively small changes of the coupling strengths in comparison to the S-waves are caused by the fact that in the S-channel short range effects are more effective.

Fig. 7 shows the half-off-shell function of the $^3P_0$ n-p partial wave where discrepancies occure for off-shell momenta $q > 2\ fm^{-1}$ within the BBS-equation.

This is mainly due to the fact that we have chosen the second interpolation energy at E_2 = 350 MeV; as a consequence, agreement of the half-off-shell function with the NN-Paris potential property improves at higher energies. The corresponding half-off-shell function, obtained within the BS-equation is in the whole off-shell-momenta domain in good agreement with the results of the NN-Paris potential.

To investigate the coupled $^3S_1$ - $^3D_1$ channel we have constructed a rank-4 approximation to the Paris potential. For the interpolation we have chosen the energies:

S-wave: $E_1 = E_D$, E_2 = 100 MeV,
D-wave: E_3 = 125 MeV, E_4 = 425 MeV,

where E_D is the binding energy of the deuteron.
The separable interaction is given by

$$V_{02}(q_0,q,k_0,k) = \begin{pmatrix} v_{01}(q_0,q) v_{02}(q_0,q) v_{03}(q_0,q) v_{04}(q_0,q) \end{pmatrix} \Delta_0 \Lambda \Delta_2 \begin{pmatrix} v_{21}(k_0,k) \\ v_{22}(k_0,k) \\ v_{23}(k_0,k) \\ v_{24}(k_0,k) \end{pmatrix} \quad (3.6)$$

with

$$\Delta_0 = \begin{pmatrix} 1000 \\ 0100 \\ 0000 \\ 0000 \end{pmatrix} \quad (3.7)$$

$$\Delta_2 = \begin{pmatrix} 0000 \\ 0000 \\ 0010 \\ 0001 \end{pmatrix} \quad (3.8)$$

$$\Lambda = \begin{pmatrix} \lambda_{11} & \lambda_{12} & \lambda_{13} & \lambda_{14} \\ \lambda_{21} & \lambda_{22} & \lambda_{23} & \lambda_{24} \\ \lambda_{31} & \lambda_{32} & \lambda_{33} & \lambda_{34} \\ \lambda_{41} & \lambda_{42} & \lambda_{43} & \lambda_{44} \end{pmatrix} \quad (3.9)$$

Each vertex function consists in this two channel problem of six terms

$$v_{0i}(q_0,q) = \sum_{j=1}^{6} \frac{C_{ij}}{(-q_0^2+q^2+\beta_{ij}^2)} \qquad (3.10)$$

$$v_{2i}(q_0,q) = \sum_{j=1}^{6} \frac{C_{ij}\, q^2}{(-q_0^2+q^2+\beta_{ij}^2)^2} \ . \qquad (3.11)$$

The additional term with respect to the other channels avoids higher orders than two in the denominater of the vertex functions responsible for the D-state. As a consequence the integration about the fourth component is much simpler as it would be if one could have orders for one degree higher. The separable interaction ((3.6)-(3.11)) of the $^3S_1$-$^3D_1$ NN-channel yields to a fairly good description of the phase shifts in the scattering domain up to 350 MeV. While the fits to the phases and the mixing parameters are shown in figures 9 - 11, the parameters of the potential are listed in table 3.

To obtain a reasonable description of the $^3S_1$ - $^3D_1$ channel within the Bethe-Salpeter-equation also, we have varied the coupling strengths λ_{ii} (i = 1 - 4). The bound state energy at -2.225 MeV was obtained by changing λ_{11} while the other three parameters were fitted to reproduce the scattering data (see table 3). The coupled channel is at least reasonably well described, although the D-wave phase shift shows some discrepancy in the low energy domain. Since this feature can also be found for the $^3D_1$ phase shift of the NN-Paris potential, one can conclude that this is no particular problem of our method.

Concerning the mixing parameter ε_1 (fig. 11), it is demonstrated that a proper description as compared to the experimental data and the results of ref. 13, where the exchange of mesons for the NN interaction was chosen, has been obtained.

The half-off-shell behaviours of the $^3S_1$ - $^3D_1$ are shown in figures 12 - 15; as in all other cases,again a good approximation to the properties of the NN-Paris potential has been achieved.

IV. Conclusion

We have presented a separable representation of the NN-Paris potential within the fully relativistic BS-equation, which incorporates the most important features of the scattering domain in the N-N case.

Concerning the scattering phase shifts we have obtained satisfactorily agreement with the experimental data of the phase shift analysis of ref.11. While these on-shell data are similar to results, obtained in an earlier investigation (ref.5) of a separable approximation of the Bethe-Salpeter equation, we have presented in this paper a separable interaction which also reproduces the half-off-shell characteristics of one of the most popular meson-theoretical NN-potentials, the NN-Paris potential. This separable potential is in favour over most of the widely used other separable potentials, which show a rather unreasonable half-off-shell behaviour.

The difference of phase shifts, obtained in the framework of the BS-equation with and without refitted coupling strengths (solid lines and dashed-dotted lines of our figures) is particularly large. It shows that the effects from the coupling between the positive and negative energy states cannot be neglected in describing the NN - interaction as it is done in the BBS-equation. By changing the coupling strengths of the separable interaction, obtained from the use of the EST method with the BBS-equation, a reasonable description of both, on-shell as well as half-off-shell properties of the NN-Paris potential had been obtained.

On behalf of this paper, fully relativistic three-body calculations should be possible.

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Table captions

Table 1: Parameters of the separable interaction in the n-p $^1S_0$ partial wave. The coupling strengths λ_i^{BBS} are results of an application of the EST-method by using the BBS-equation; λ_i^{BS} are the refitted values within the BS-framework.

Table 2: Parameters of the separable interactions in the $^1P_1$, $^3P_0$ and $^3P_1$ partial waves. The parameters λ_i^{BS} and λ_i^{BBS} are defined in table caption of table 1.

Table 3: Parameters of the separable interaction in the coupled $^3S_1$ - $^3D_1$ partial wave state. The parameters λ_i^{BS} and λ_i^{BBS} are defined in table caption of table 1.

β (fm^{-1})	C_{1i} (fm^{0})	C_{2i} (fm^{0})	C_{3i} (fm^{0})	λ (fm^{-4})
β_1 = 1.1000	C_{11} = 35.741609	C_{21} = 48.037979	C_{31} = 81.570514	λ_1^{BBS} = -1. λ_1^{BS} = -1.083
β_2 = 1.9965421	C_{12} = 1032.6580	C_{22} = 116.71817	C_{32} = 2886.0197	λ_2^{BBS} = -1. λ_2^{BS} = -1.52659
β_3 = 2.8295473	C_{13} = 8225.6013	C_{23} = 3390.4081	C_{33} = 18329.260	λ_3^{BBS} = 1. λ_3^{BS} = 0.538
β_4 = 3.6238004	C_{14} = 17430.832	C_{24} = 8110.3219	C_{34} = 35577.737	
β_5 = 4.3904282	C_{15} = 10568.521	C_{25} = 4923.0097	C_{35} = 20594.912	

TABLE 1

ß (fm^{-1})	C (fm^{0})		λ (fm^{-4})
	$^{1}P_{1}$		
$ß_1$ = 0.7	C_{11} = 0.69612928	C_{21} = 3.8759838	λ_1^{BBS} = 1.
$ß_2$ = 1.4	C_{12} = 27.246204	C_{22} = 387.30146	λ_2^{BBS} = 1.
$ß_3$ = 2.1	C_{13} = 538.28592	C_{23} = 2945.2732	λ_1^{BS} = 0.950000
$ß_4$ = 2.8	C_{14} = 1848.8997	C_{24} = 6658.5553	λ_2^{BS} = 0.9068131
$ß_5$ = 3.5	C_{15} = 1980.6184	C_{25} = 4991.4279	
	$^{3}P_{0}$		
$ß_1$ = 0·8	C_{11} = 2.4716627	C_{21} = 8.9120797	λ_1^{BBS} = -1.
$ß_2$ = 1.6	C_{12} = 211.31836	C_{22} = 666.77157	λ_2^{BBS} = 1.
$ß_3$ = 2.4	C_{13} = 313.92385	C_{23} = 7266.8332	λ_1^{BS} = -1.05200
$ß_4$ = 3.2	C_{14} = 3228.2158	C_{24} = 20055.583	λ_2^{BS} = 0.850415
$ß_5$ = 4.0	C_{15} = 2695.7289	C_{25} = -13461.244	
	$^{3}P_{1}$		
$ß_1$ = 1.0	C_{11}= 0.36155904	C_{21}= -5.6466263	λ_1^{BBS} = 1.
$ß_2$ = 1.866066	C_{12}= 1088.8383	C_{22}= 511.77353	λ_2^{BBS} = 1.
$ß_3$ = 2.6878754	C_{13}= -9490.2618	C_{23}= -3661.759	λ_1^{BS} = 0.900625
$ß_4$ = 3.4822022	C_{14}= 21167.417	C_{24}= 10752.023	λ_2^{BS} = 0.960000
$ß_5$ = 4.2566996	C_{15}= -13723.185	C_{25}= -8810.46	

TABLE 2

β (fm^{-1})	C (fm^{0})	λ (MeV fm^{-1})	β (fm^{-1})	C (fm^{0})
l = 0			l = 2	
β_{11} = 1.0	C_{11} = 15.659827	λ_{11}^{BBS} = -0.22756747	β_{11} = 1.0	C_{11} = -3.025362
β_{12} = 1.866066	C_{12} = -1673.2143	λ_{12} = -.14415510	β_{12} = 1.866066	C_{12} = -390.33049
β_{13} = 2.6878754	C_{13} = 19597.873	λ_{13} = 0.06289203	β_{13} = 2.6878754	C_{13} = 2615.2074
β_{14} = 3.4822022	C_{14} = -98548.033	λ_{14} = 0.00374014	β_{14} = 3.4822022	C_{14} = -11652.333
β_{15} = 4.2566996	C_{15} = 229712.92	λ_{21} = -0.1441551	β_{15} = 4.2566996	C_{15} = 17488.783
β_{16} = 4.7	C_{16} = -151345.61	λ_{22}^{BBS} = 0.11398121	β_{16} = 4.7	C_{16} = -7066.9205
β_{21} = 0.8	C_{21} = 49.801112	λ_{23} = 0.085399964	β_{21} = 0.7	C_{21} = 2.8135543
β_{22} = 1.4928528	C_{22} = -2072.196	λ_{24} = -0.078046366	β_{22} = 1.3062462	C_{22} = -311.48349
β_{23} = 2.1503003	C_{23} = 6637.7315	λ_{31} = 0.062892029	β_{23} = 1.8815127	C_{23} = 4450.8549
β_{24} = 2.7857618	C_{24} = 1773.5598	λ_{32} = 0.085399963	β_{24} = 2.4375415	C_{24} = -16680.498
β_{25} = 3.4053597	C_{25} = -20763.725	λ_{33}^{BBS} = -0.028782675	β_{25} = 2.9796897	C_{25} = 25938.388
β_{26} = 4.0126022	C_{26} = 14768.319	λ_{34} = -0.033827124	β_{26} = 3.5110269	C_{26} = -14081.186
		λ_{41} = 0.0037401414		
β_{31} = 1.0	C_{31} = -25.801849	λ_{42} = -0.078046364	β_{31} = 0.6	C_{31} = 2.3495167
β_{32} = 1.866066	C_{32} = 2461.253	λ_{43} = -0.033827124	β_{32} = 1.2	C_{32} = -304.5283
β_{33} = 2.6878754	C_{33} = -24133.622	λ_{44}^{BBS} = 0.17871437	β_{33} = 1.8	C_{33} = 4578.6541
β_{34} = 3.4822022	C_{34} = 48591.603	λ_{11}^{BS} = -0.2441536	β_{34} = 2.4	C_{34} = -12876.067
β_{35} = 4.2566996	C_{35} = -25019.227	λ_{22}^{BS} = 0.1336423	β_{35} = 3.0	C_{35} = 5247.3456
β_{36} = 4.7	C_{36} = -1532.4468	λ_{33}^{BS} = -0.0268	β_{36} = 3.6	C_{36} = 4576.4304
β_{41} = 0.8	C_{41} = -26.818673	λ_{44}^{BS} = 0.175	β_{41} = 0.6	C_{41} = -1.5935462
β_{42} = 1.6	C_{42} = 2433.8912		β_{42} = 1.1196396	C_{42} = 120.3399
β_{43} = 2.4	C_{43} = -31119.533		β_{43} = 1.6127252	C_{43} = -1295.0393
β_{44} = 3.2	C_{44} = 114977.15		β_{44} = 2.0893213	C_{44} = 3342.7168
β_{45} = 4.0	C_{45} = -171593.24		β_{45} = 2.5540198	C_{45} = -1195.6997
β_{46} = 4.7	C_{46} = 86586.506		β_{46} = 2.0094517	C_{46} = -1184.5975

TABLE 3

Figure captions

Figures 1, 3, 4, 5, 9 and 10:

Scattering phase shifts of the NN system.
The solid line represents the calculation within the BS-equation with refitted coupling strengths λ_i^{BS}, the dashed dotted line shows the result of the BS-investigation without refitting λ_i^{BBS}. The dashed line describes the NN-Paris potential calculation and the dotted line shows the results of the EST-method, applied in the BBS-framework.
The circles indicate the experimental values of ref.11

Figure 11: **Mixing parameter ε_1 of the $^3S_1$ - $^3D_1$ coupled state.**
The solid line represents the calculation within the BS-equation with refitted coupling strengths λ_i^{BS}, the dashed dotted line shows the result of the BS-investigation without refitting λ_i^{BBS}. The dashed line describes the NN-Paris potential calculation and the dotted line shows the results of the EST-method, applied in the BBS-framework.
The experimental values (ɸ) are taken from ref.12 and (┼) from ref. 14

Figures 2, 6, 7, 8, 12, 13, 14 and 15:

Half-off-shell functions of the NN-system at E_{lab}= 100 M
The solid line shows the result of the BS-investigation with refitted coupling strengths λ_i^{BS}, the dotted line represents the results of the EST-method, applied in the BBS-framwork and the dashed line corresponds to the calculation of the NN-Paris potential.

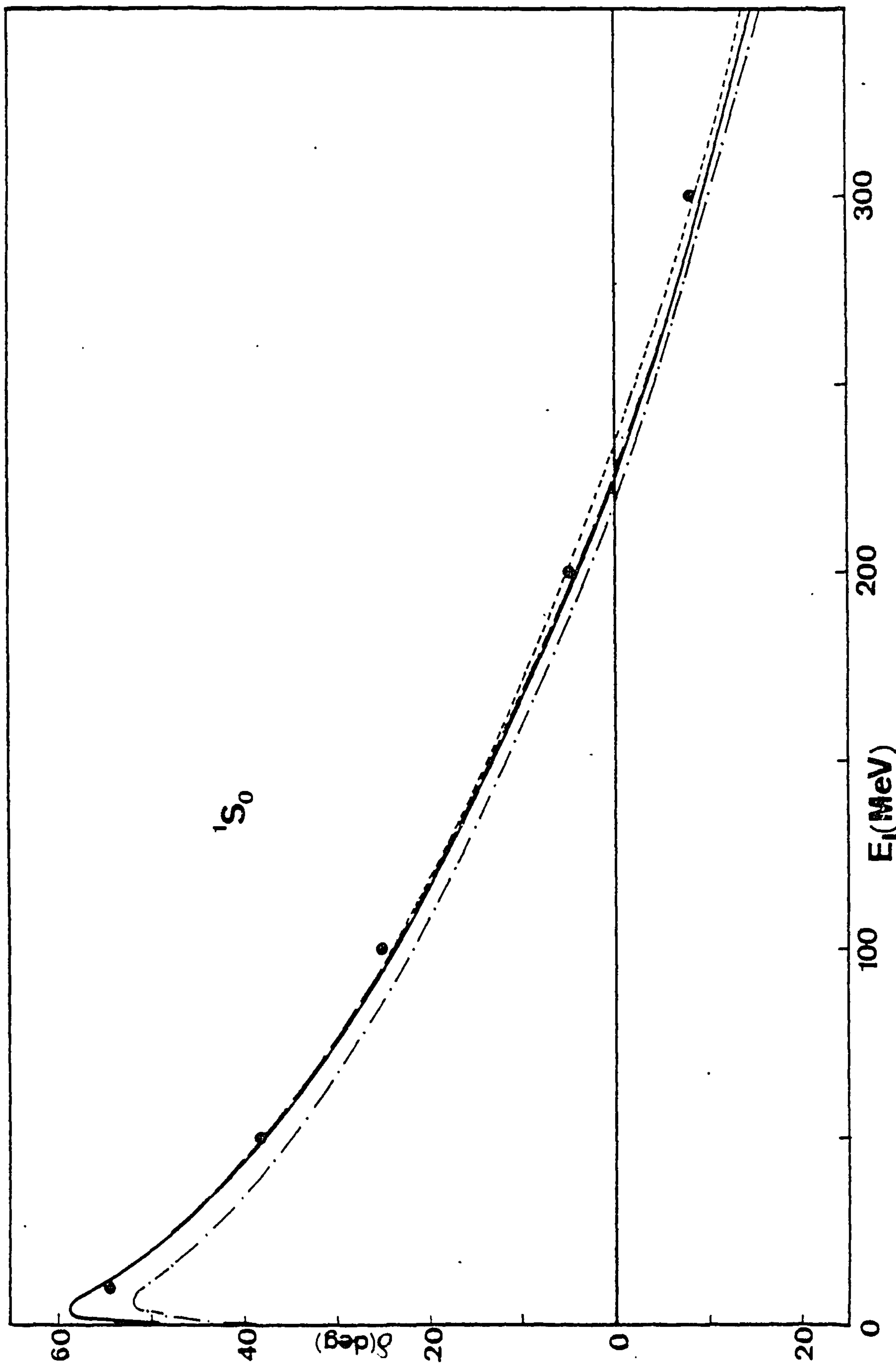

fig. 1

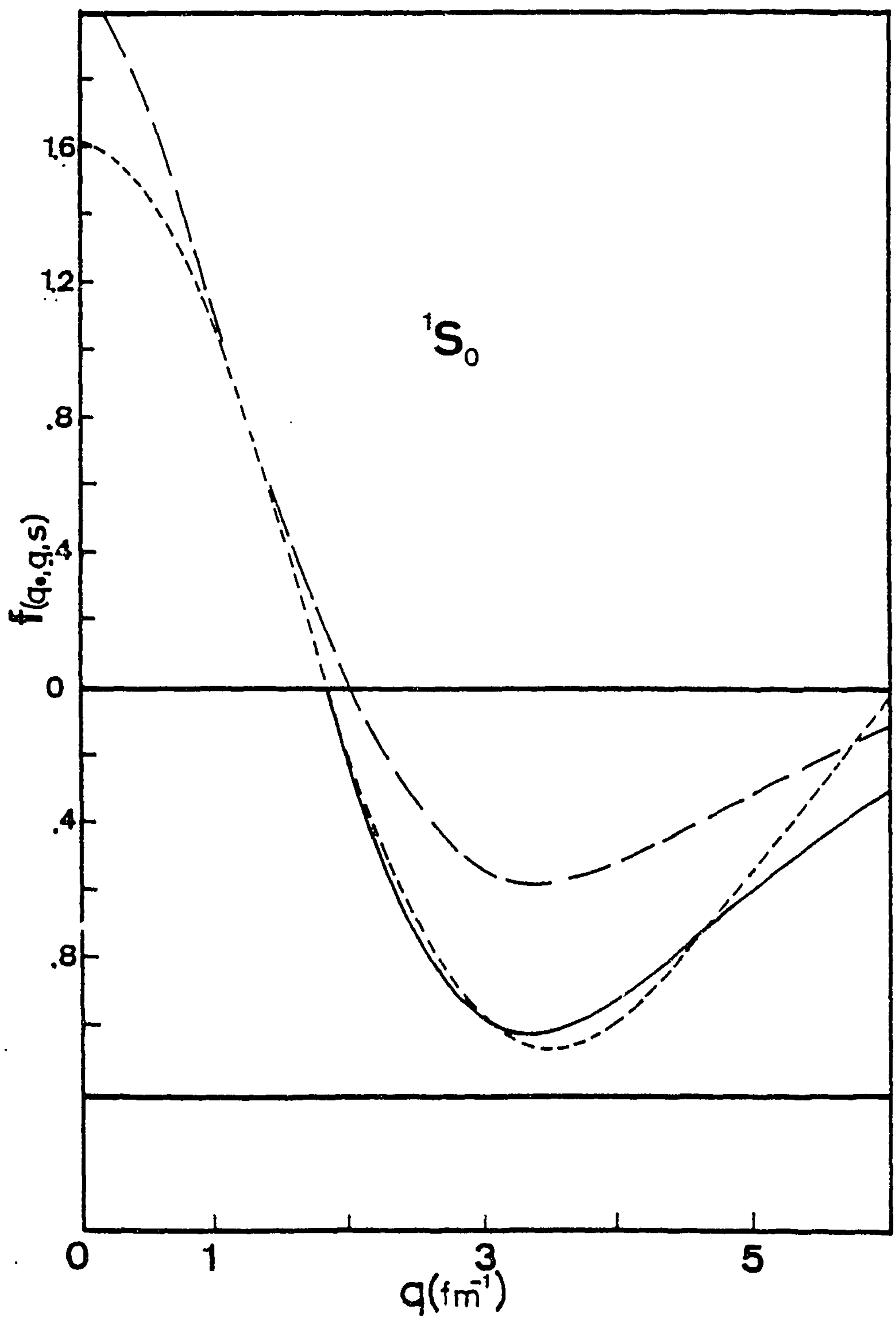

fig. 2

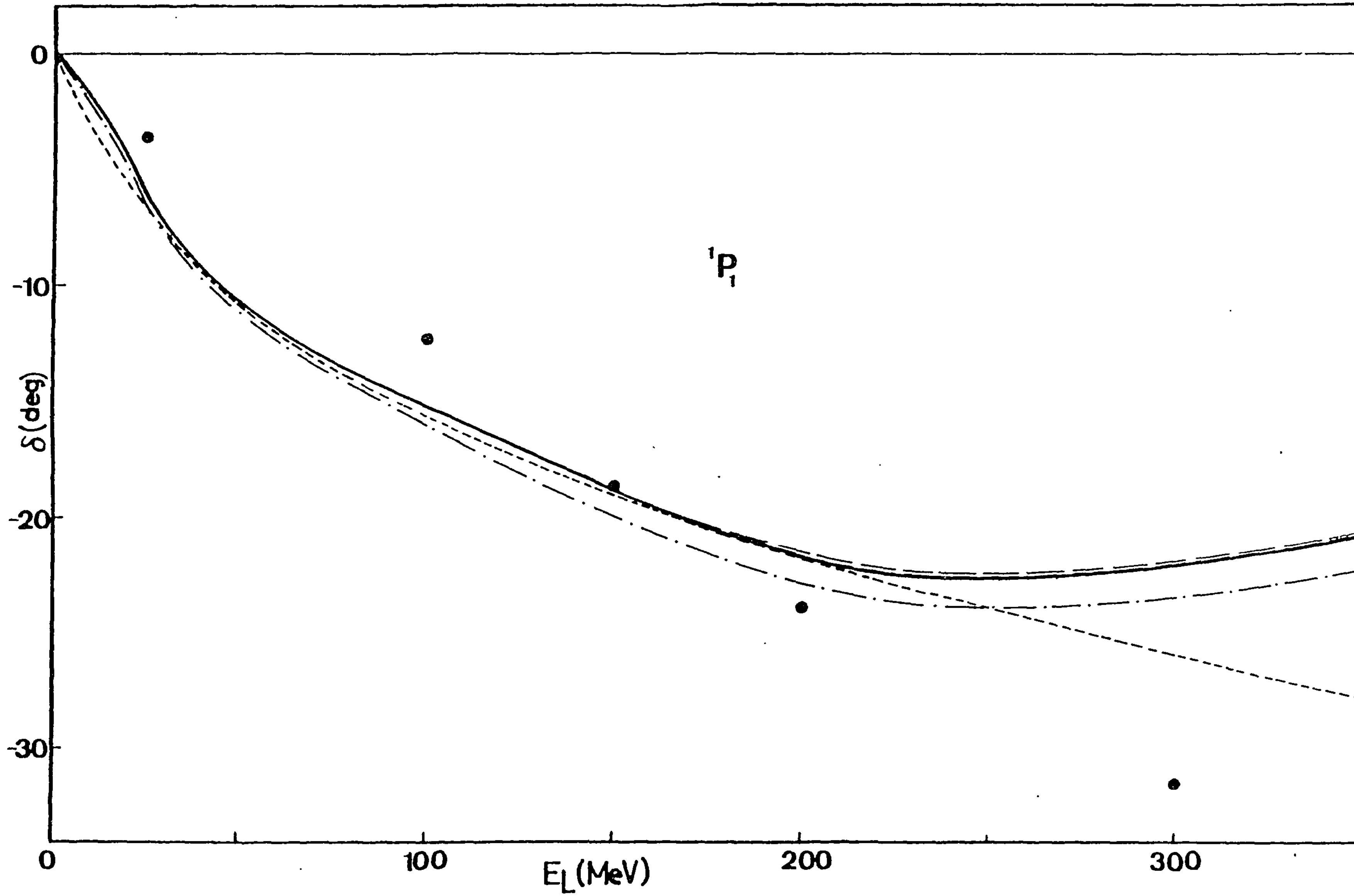

fig. 3

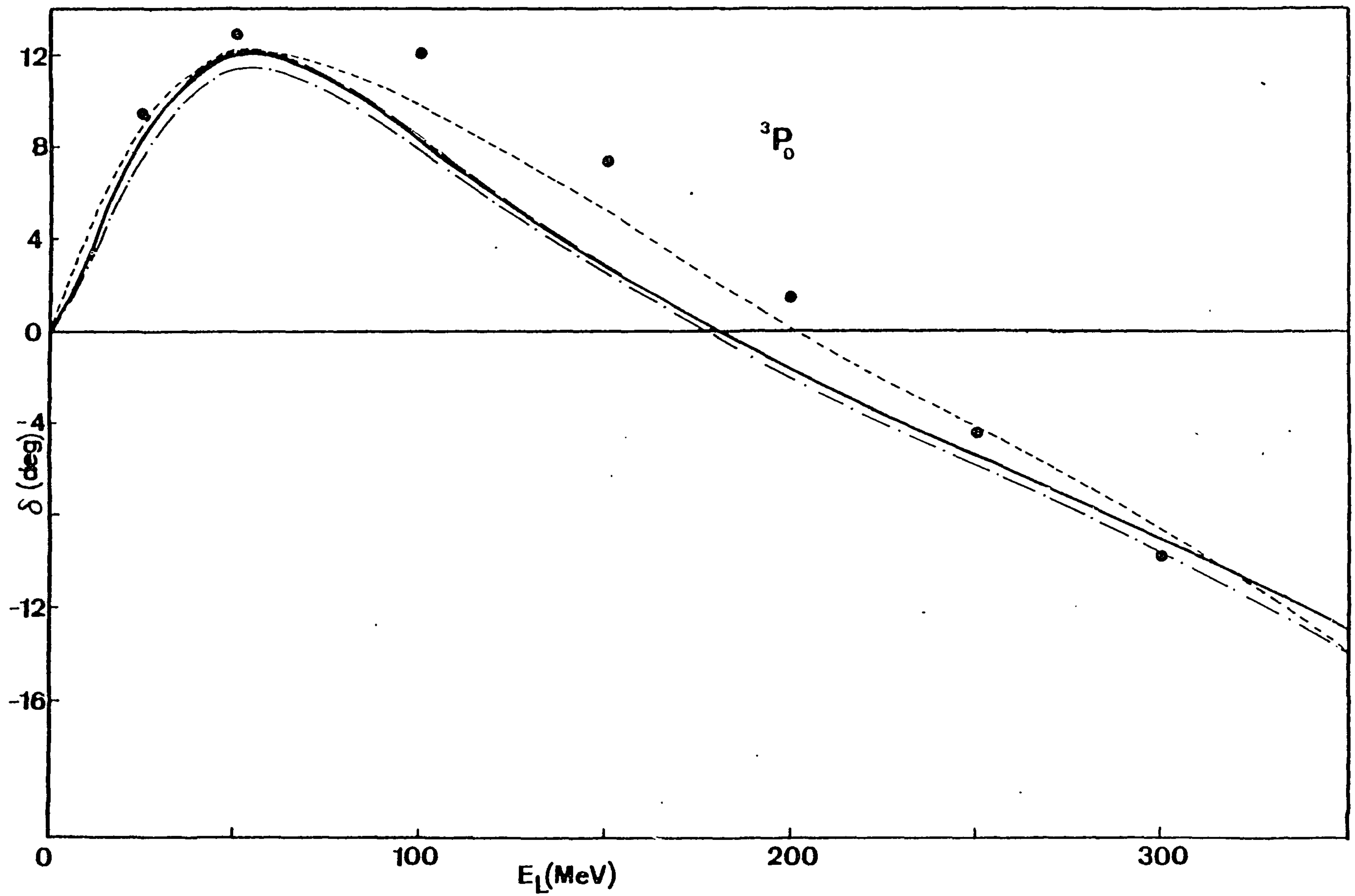

fig. 4

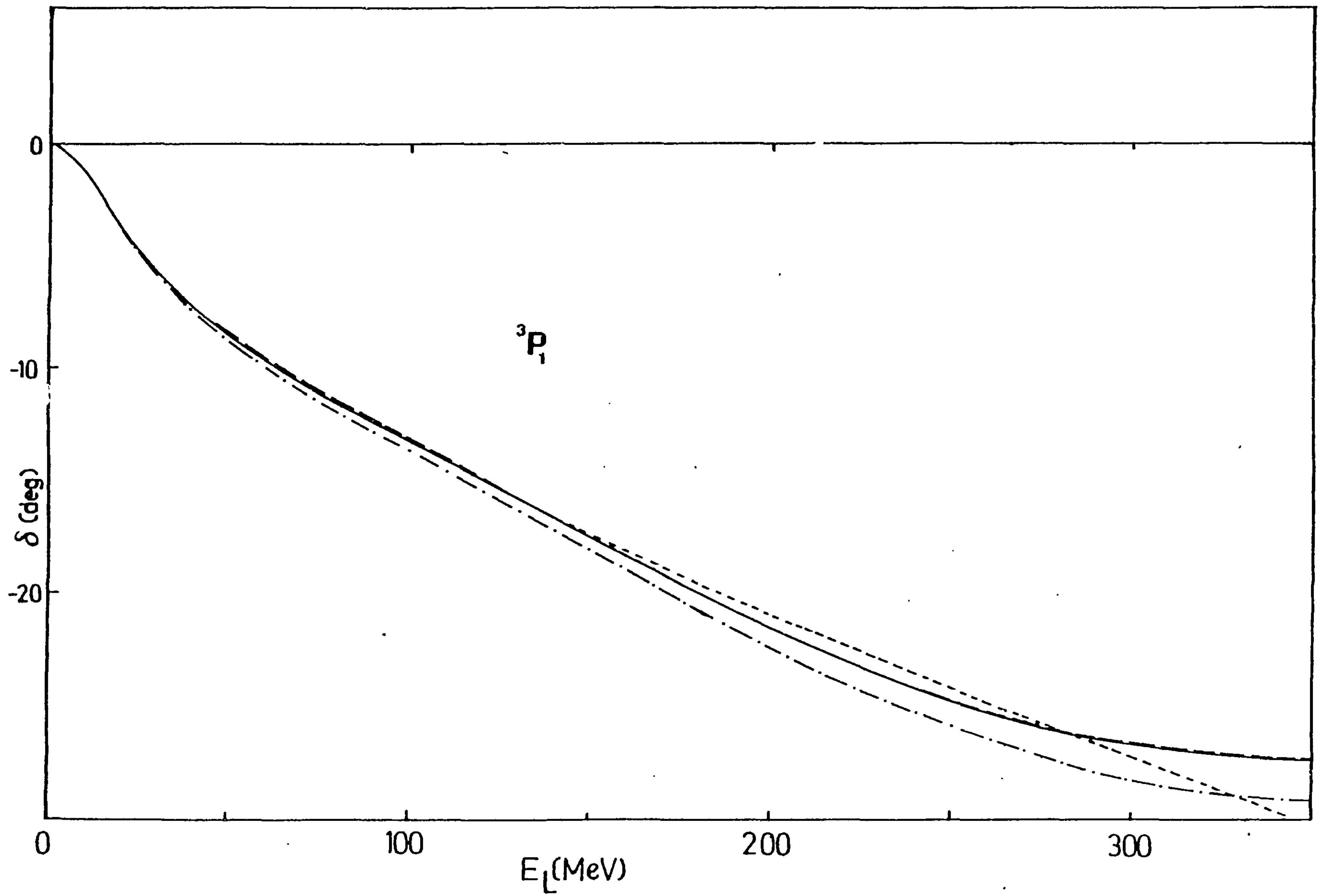

fig. 5

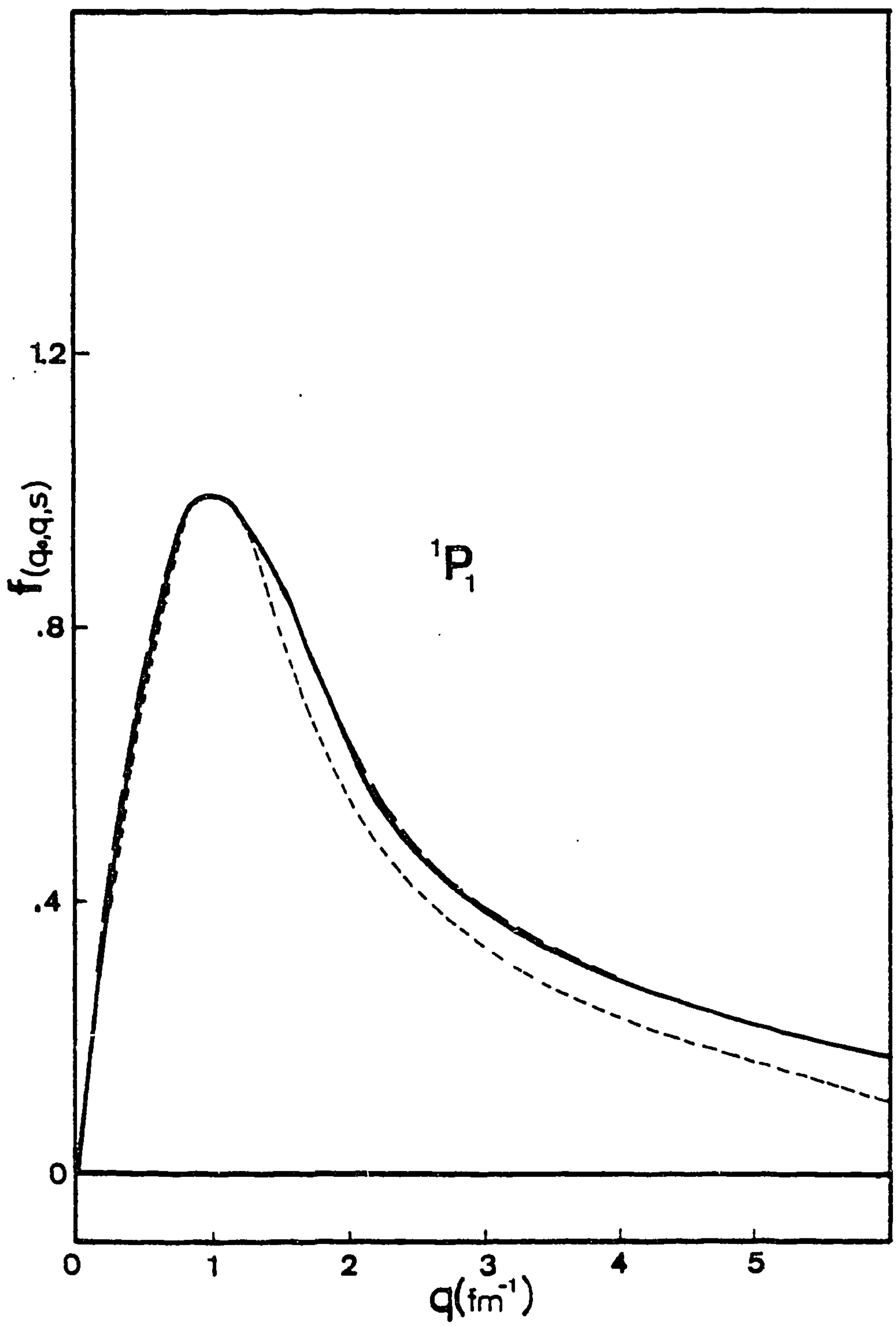

fig. 6

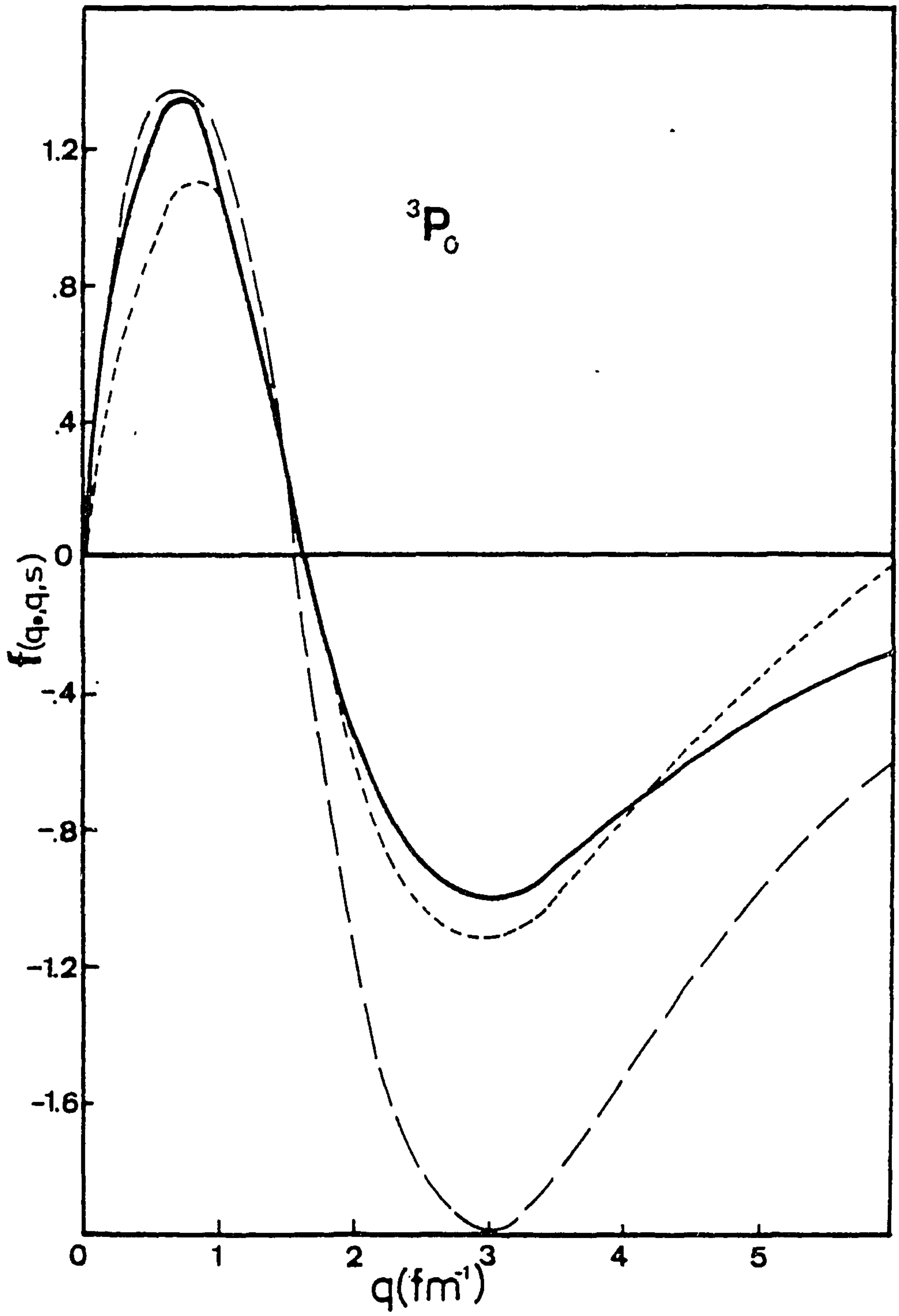

fig. 7

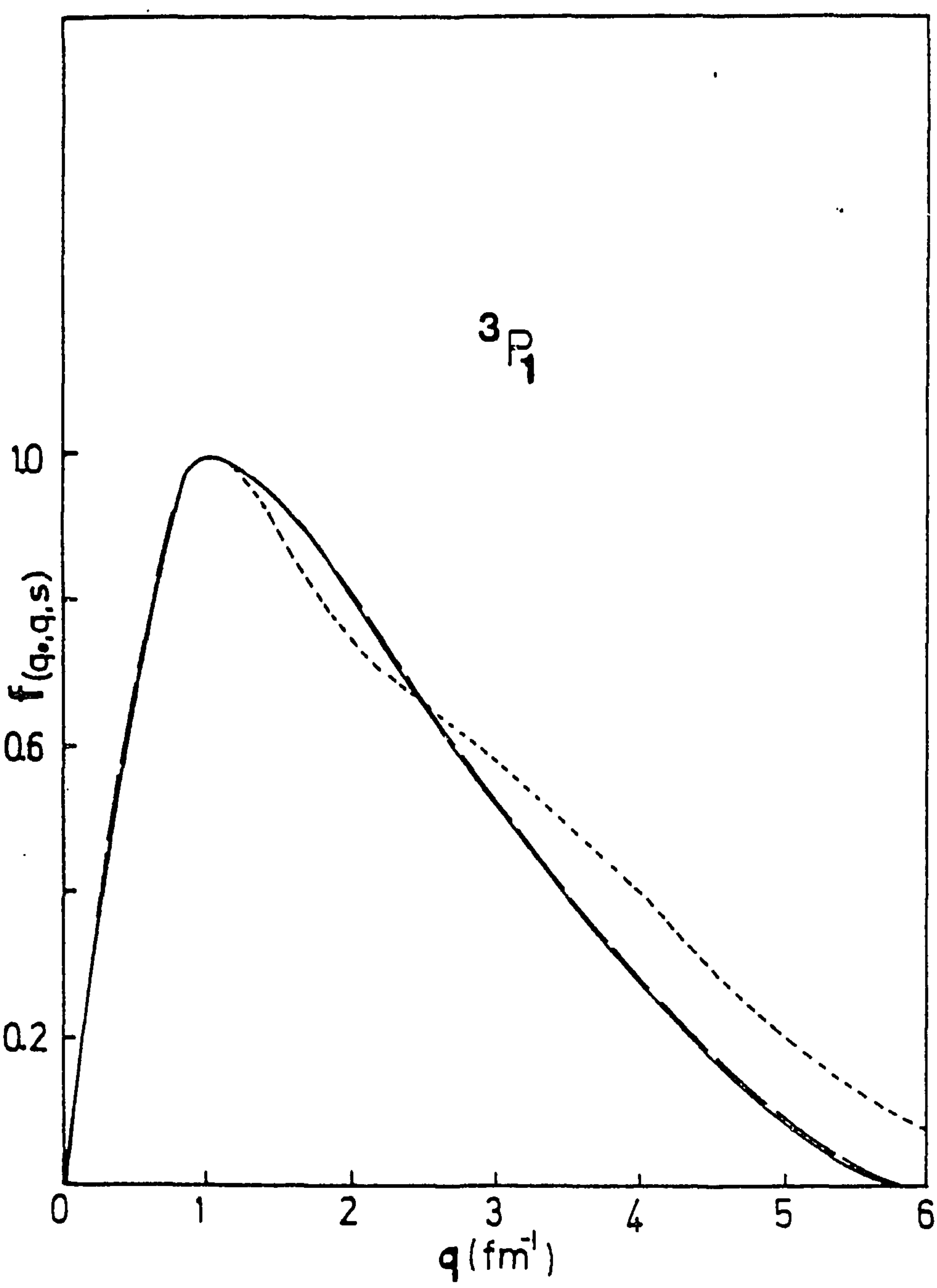

fig. 8

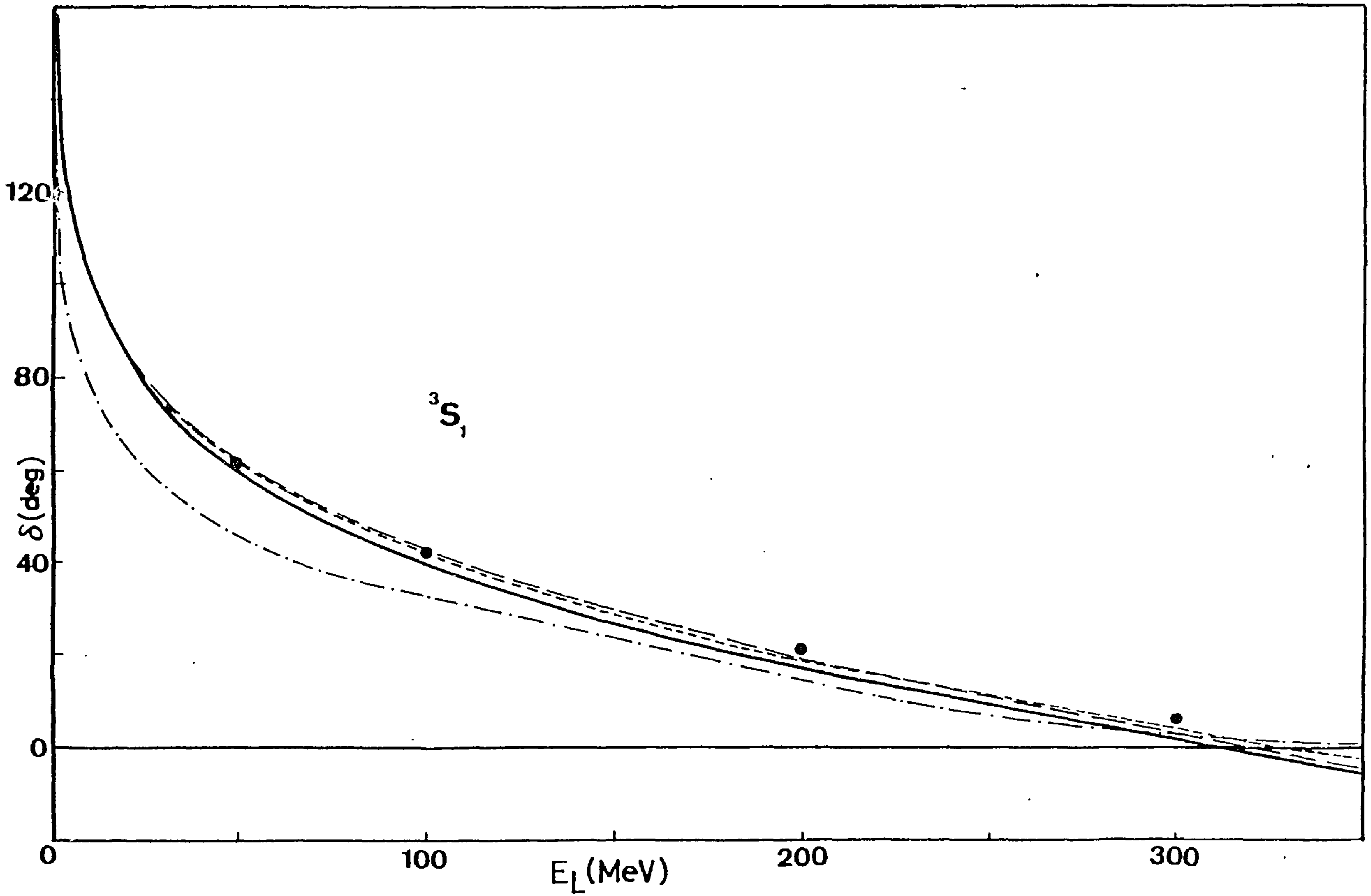

fig. 9

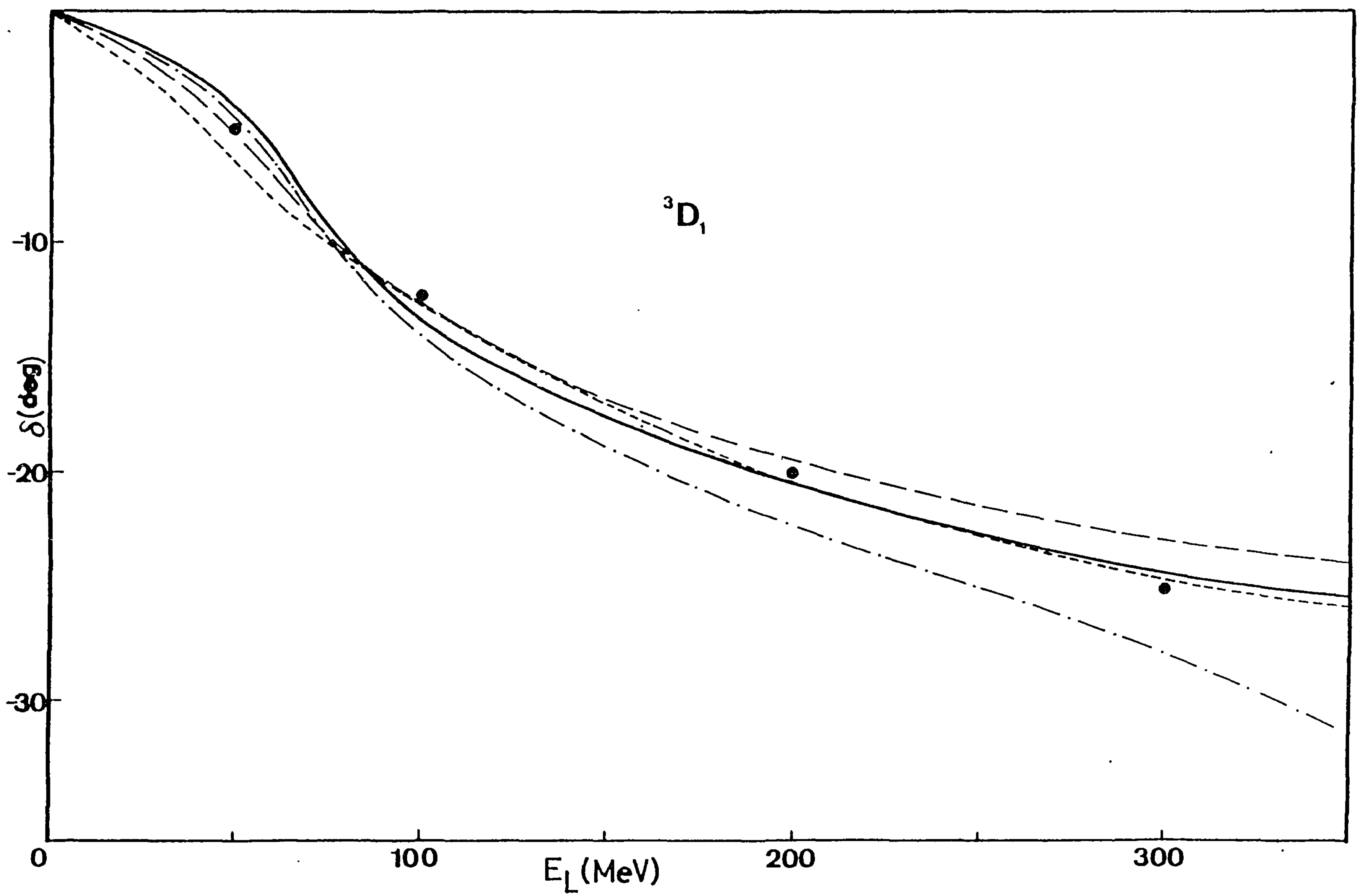

fig. 10

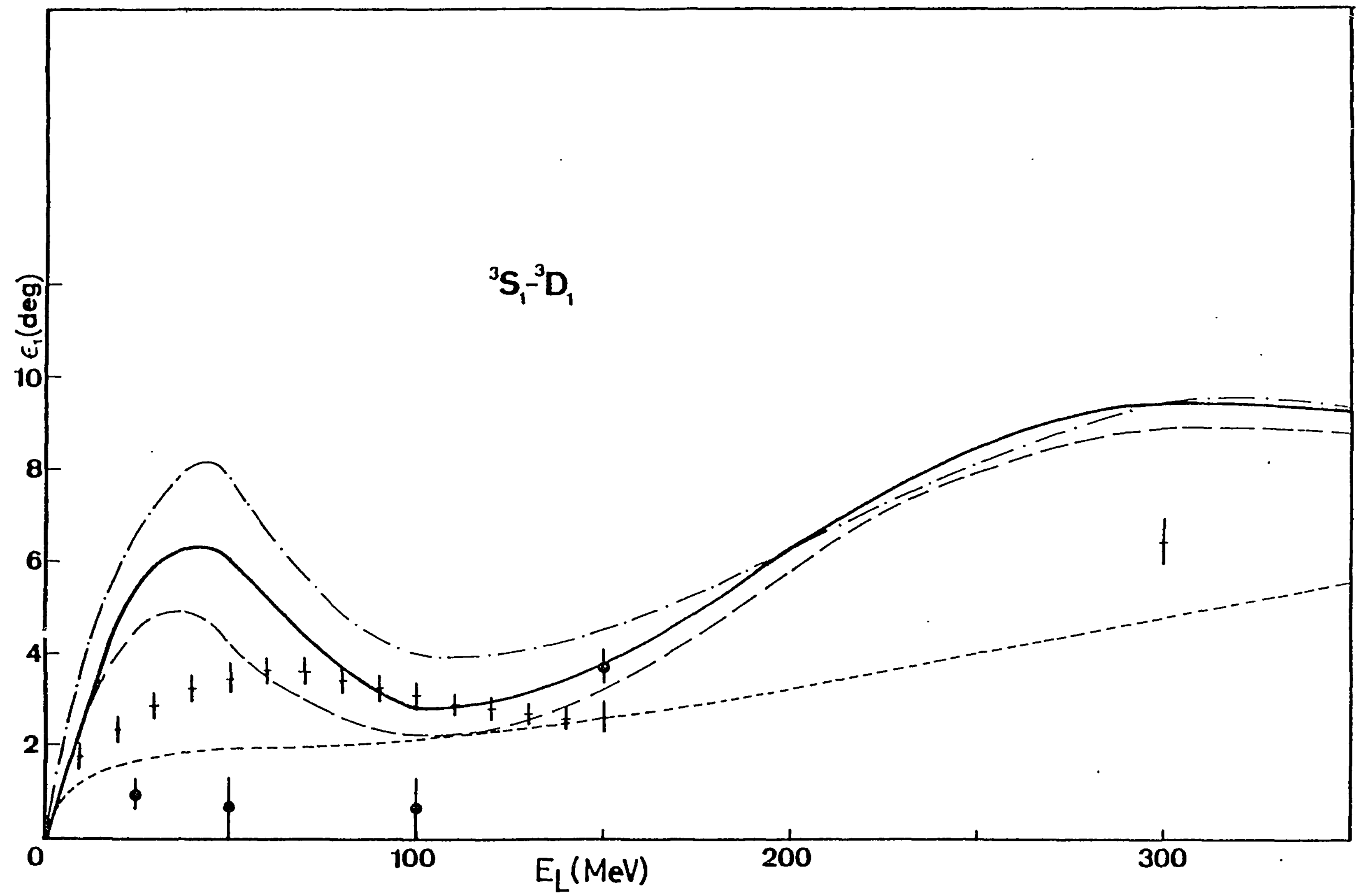

fig. 11

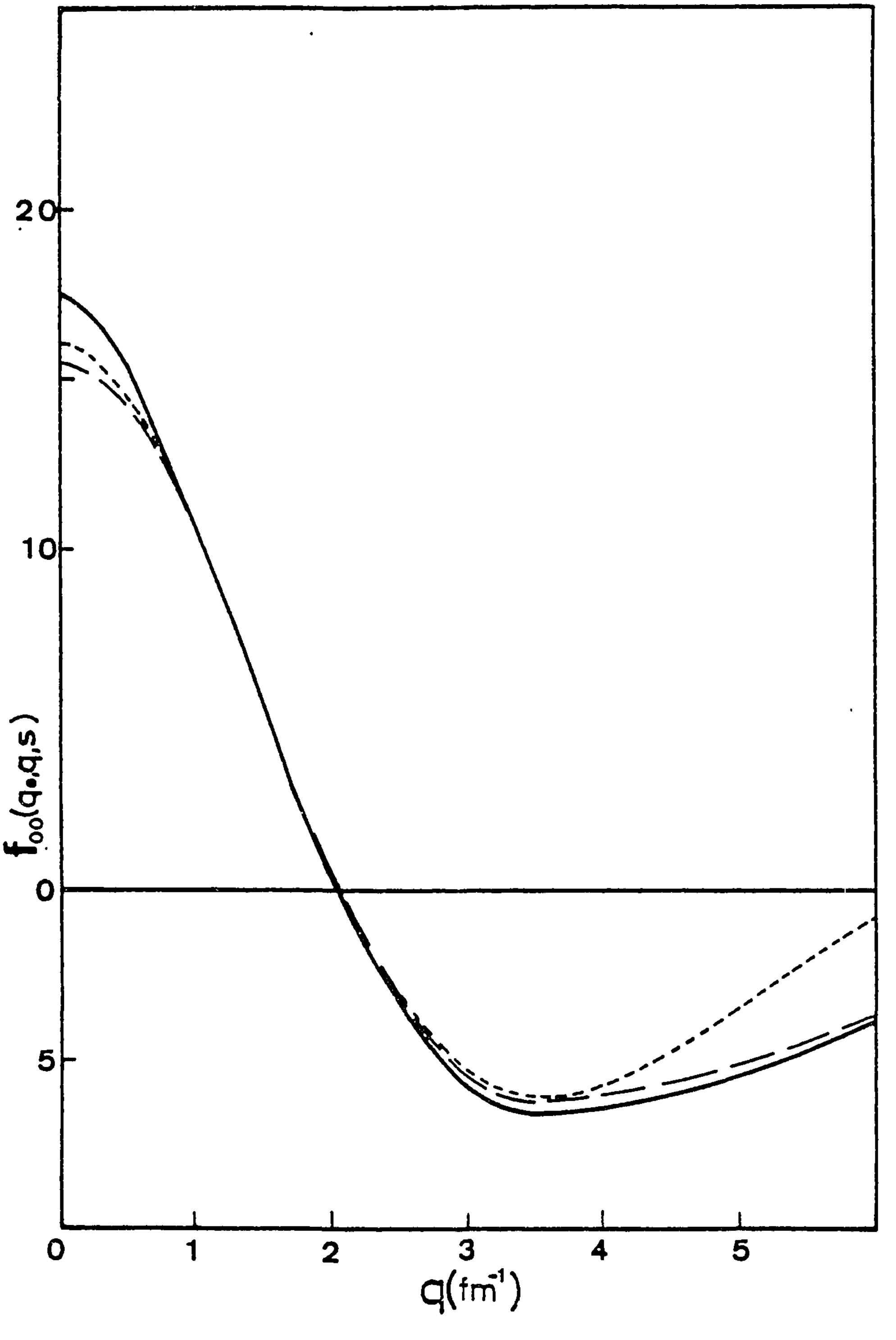

fig. 12

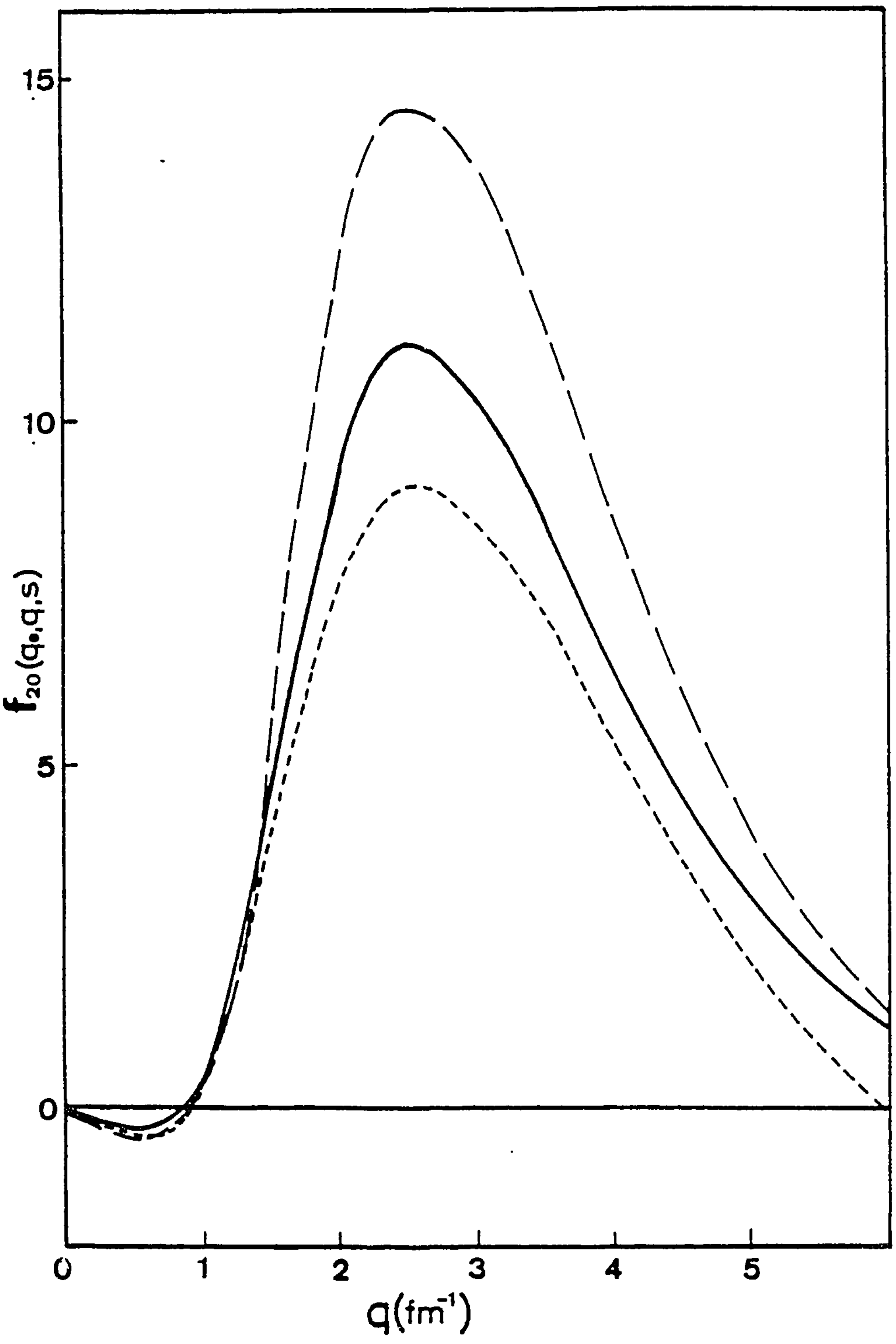

fig. 13

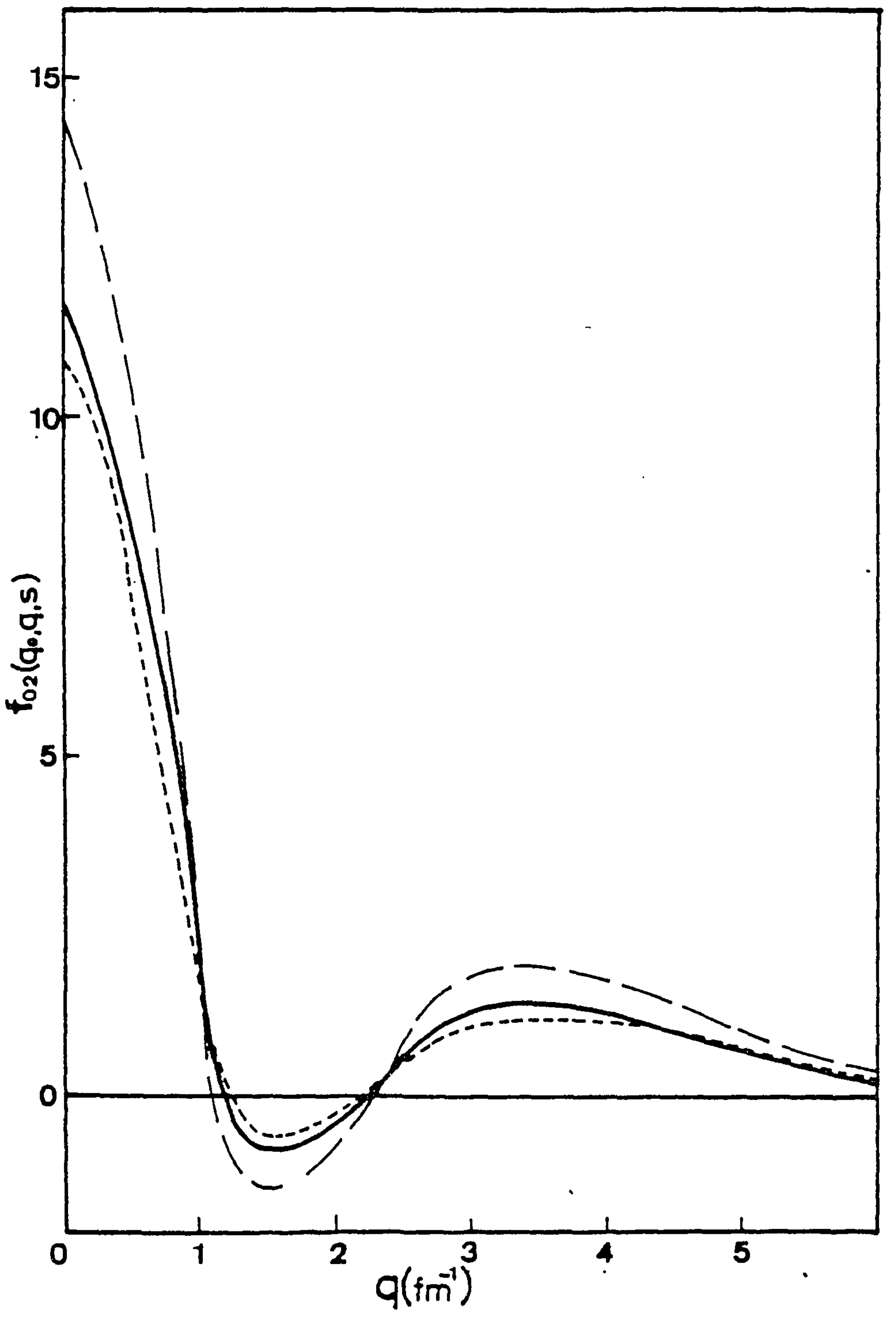

fig. 14

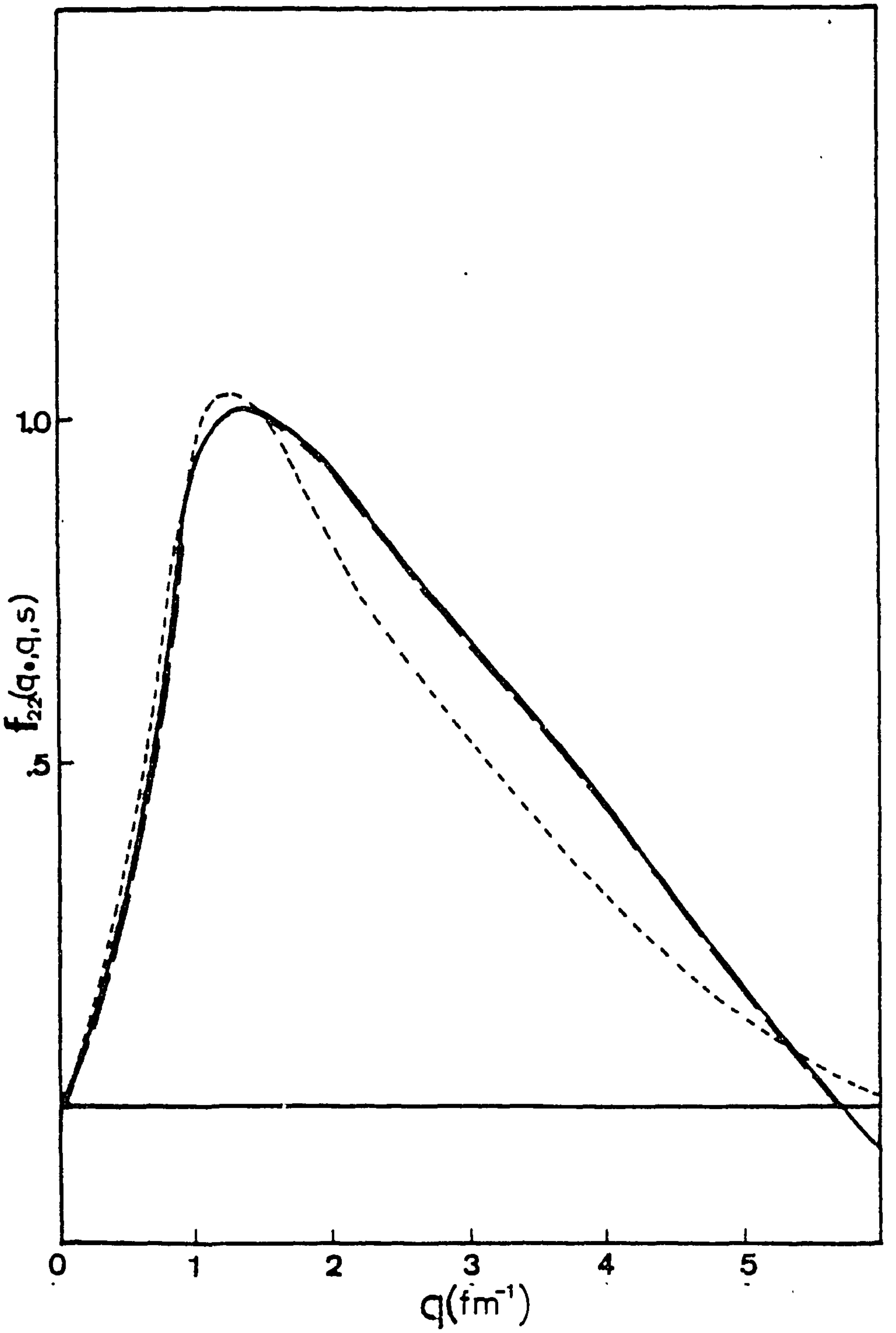

fig. 15

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