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Comment on Macroscopic Analysis of (p,n) Reactions*

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The extraction of the isovector part of the optical potential from nucleon-nucleus optical potentials is discussed when the optical potentials are energy dependent.

The Lane model[1] of the nucleon-nucleus optical potential gives a simple description of the (p,n) reaction to isobaric analog states as a quasi-elastic scattering process. In this model the dependence of the optical potential upon isospin is

$$U = U_o + \underset{\sim}{t} \cdot \underset{\sim}{T}\, U_1/A \qquad (1)$$

where $\underset{\sim}{t}$ is the projectile isospin operator and $\underset{\sim}{T}$ is the nuclear isospin operator. The proton elastic, neutron elastic, and (p,n) quasi-elastic potentials are evaluated from Eq. (1) and are

$$U_p = U_o - (N-Z)\, U_1/4A \qquad (2)$$

$$U_n = U_o + (N-Z)\, U_1/4A \qquad (3)$$

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$$U_{pn} = (N-Z)^{\frac{1}{2}} U_1/2A \qquad (4)$$

In a recent paper[2] one of us (GWH) attempted to extract the isospin dependent term, U_1, by simply taking the difference between the neutron and proton optical potentials at the neutron and proton energies involved in the reaction. It was asserted that this procedure describes the energy dependence of the (p,n) reaction on ^{208}Pb and ^{209}Bi. However, the scheme contains implicit assumptions which need to be spelled out before it can truly be considered to provide a useful charge-independent form factor. Moreover, we will show that the success in fitting the (p,n) excitation functions is due primarily to the use of neutron parameters derived from low energy neutron elastic scattering rather than from the use of a particular form factor.

When a parametrization of the nucleon-nucleus optical potentials over a range of nuclei and energies has been obtained, U_1 may in principle be extracted in a straightforward way. However, when a parametrization for only a single nucleus is obtained, one is forced to make assumptions concerning the division of the energy dependence between the isoscalar and isovector parts of the optical potentials. In particular, a typical parametrization[3] of the nuclear optical potentials for the target nucleus, A, is

$$U_{pA} = U_o - U_o'(E_p) - \xi U_1(E_p) + U_c \qquad (5)$$

$$U_{nA} = U_o - U_o'(E_n) + \xi U_1(E_n) \qquad (6)$$

where U_o' contains the explicit energy dependence of the isoscalar part of U, U_c is the Coulomb correction term for the proton potential due to this energy dependence and $\xi=(N-Z)/4A$. The magnitude of U_c for ^{208}Pb is nearly 10% of the real part of U and is nearly the same size as the symmetry term, U_i. To extract an average U_1 from (5) and (6) we have:

$$\bar{U}_1 = \frac{1}{2\xi}\left[U_{nA}(E_n) - U_{pA}(E_p) + \Delta U_1\right] \qquad (7)$$

where

$$\Delta U_1 = U_c + U_o'(E_p) - U_o'(E_n). \qquad (8)$$

Thus only if ΔU_1 vanishes can we obtain Eq. (7) of Ref. 2. Since the usual parametrizations of the optical potentials contain only a real Coulomb correction term, U_c, and a complex energy dependence in U_o', only the real part of ΔU_1 can possibly be cancelled unless one assumes that the entire imaginary part of the energy dependence of U is contained in U_1. This assumption is not justified as shown by careful analyses[4] of optical model parameters for N=Z nuclei.

We now show that the quasi-elastic (p,n) cross sections on ^{208}Pb are not very sensitive to the precise form factor used to calculate the transition. In Fig. 1 we show the angular distributions[5] for 26 MeV protons on ^{208}Pb using the solution to the coupled Lane equations.[2] However, we do not make any attempt to make the (p,n) coupling term consistent within the Lane model. The proton optical potentials are taken from the Becchetti and Greenlees (BG) best fit parameter set[3] and, rather than extrapolating the BG neutron parameters to such low energies and correcting for compound nucleus effects, we use the neutron parameters from the study of Fu and Perey[6] (FP). These are shown in Table I. Curve A uses the symmetry term of the BG parameters multiplied by a factor of 0.9 for the coupling form factor. Curve B has been calculated using a form factor derived from a two-nucleon effective interaction of Yukawa form with a range of 1 F and a strength of 16 MeV. In curve C we use the prescription of Ref. 2 for the form factor. Since the dependence of the cross section upon the imaginary part of the form factor is weak in the Pb region of the periodic table, there is very little difference between the three cases.

We now calculate the energy dependence of the total cross section for the same three cases of Fig. 1 and compare with data.[7] These are shown in Fig. 2. Due to the uncertainties in the normalization of this data, we have normalized to the total cross section of Schery[5] at 26 MeV. Since the FP neutron parameters may not be applicable above 16 MeV (E_p=35 MeV), we use the BG neutron parameters (also given in Table I) above this energy.[8] As for the angular distributions, the data really does not allow us to choose between the form factors A-C and the use of proton and neutron optical parameters which best fit the elastic scattering at the appropriate energies appears to be sufficient to explain the energy dependence of the total (p,n) cross sections.

TABLE I. Optical model parameters used in Figures 1 and 2.

	V_R(MeV)	W_V(MeV)	W_D(MeV)	V_{so}(MeV)	r_o(F)	a(F)	r_o'(F)	a'(F)	r_o''(F)	a''(F)
$(p+^{208}Pb)$BG	$64.6-.32\ E_p$	$.22\ E_p-2.7$	$14.3-.25\ E_p$	6.2	1.17	0.75	1.32	0.657	1.01	0.75
$(n+^{208}Pb)$FP	$47.0-.25\ E_n$	0	$3.5+.43\ E_n$	6.0	1.25	0.65	1.25	0.470	1.25	0.65
$(n+^{208}Pb)$BG	$48.9-.32\ E_n$	$.22\ E_n-2.7$	$9.15-.25\ E_n$	6.2	1.17	0.75	1.32	0.657	1.01	0.75

$$V(r) = -V_R f(x) - W_V f(x') + 4W_D \frac{df(x')}{dx'} + V_{so}\left(\frac{\hbar}{m_\pi c}\right)^2 \frac{1}{ra''} \frac{df(x'')}{dx''} \underset{\sim}{L} \cdot \underset{\sim}{\sigma}$$

$$f(x) = [1 + \exp\ (x)]^{-1}$$

$$x = \frac{r-r_o A^{1/3}}{a} \qquad x' = \frac{r-r_o' A^{1/3}}{a'} \qquad x'' = \frac{r-r_o'' A^{1/3}}{a''}$$

References

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[2] G. W. Hoffmann, Phys. Rev. C 8, 761 (1973).

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[6] C. Y. Fu and F. G. Perey, Oak Ridge National Laboratory, Report No. ORNL-4765, 1972 (unpublished).

[7] G. W. Hoffmann, W. H. Dunlop, G. J. Igo, J. G. Kulleck, C. A. Whitten, and W. R. Coker, Phys. Lett. 40B, 453 (1972).

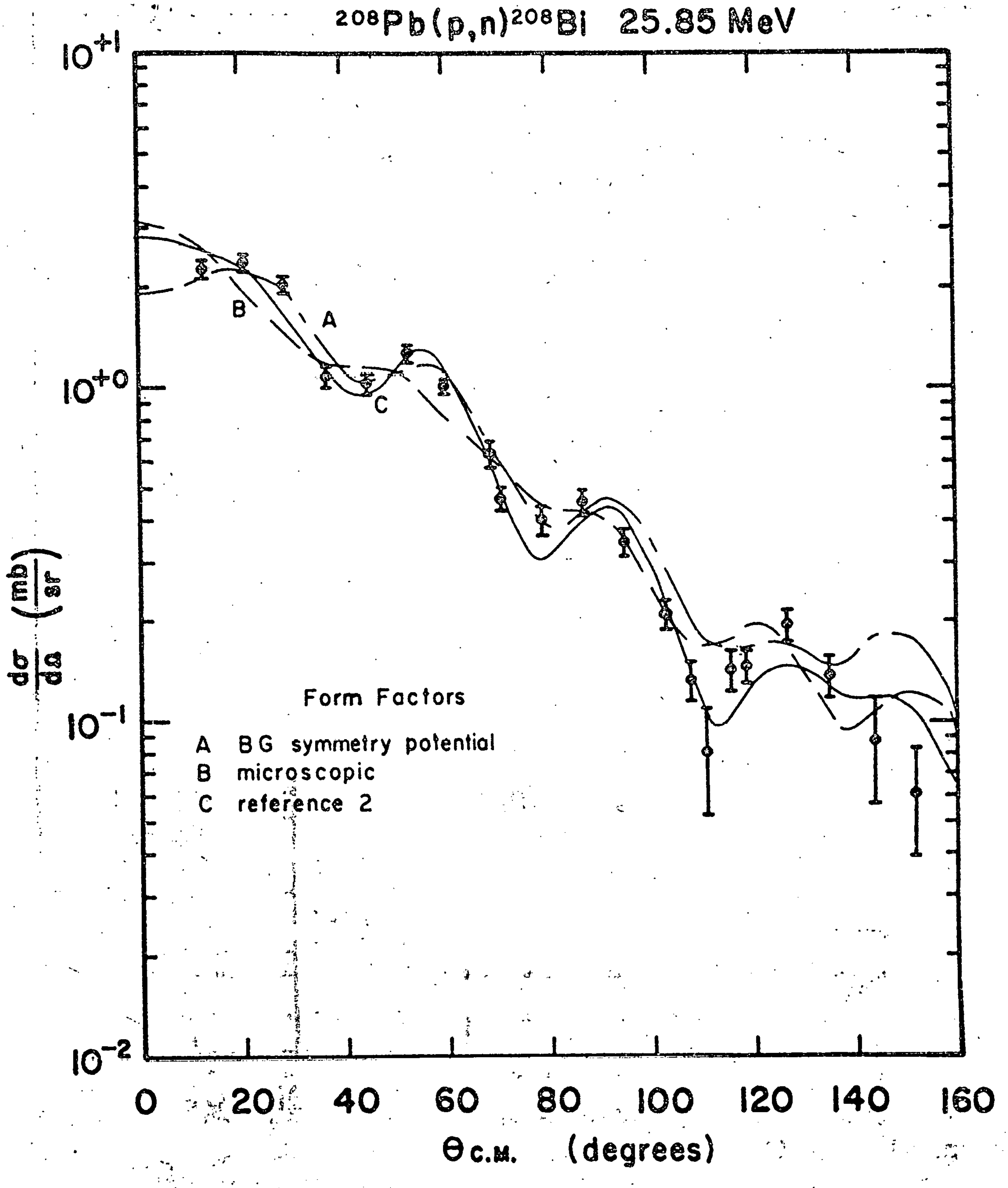
[8] The apparent good fit of Fig. 6 of Ref. 2, which uses FP parameters at all energies, is due to the fact that the energy dependence of the real part of the form factor used there and shown in Fig. 3 of Ref. 2 is in error. It is apparent from curve C that when these two errors are corrected, the fit is as satisfactory as (if not better at the lower energies than) in Ref. 2.

[9] G. W. Hoffmann and W. R. Coker, Phys. Rev. Lett. 29B, 227 (1972).

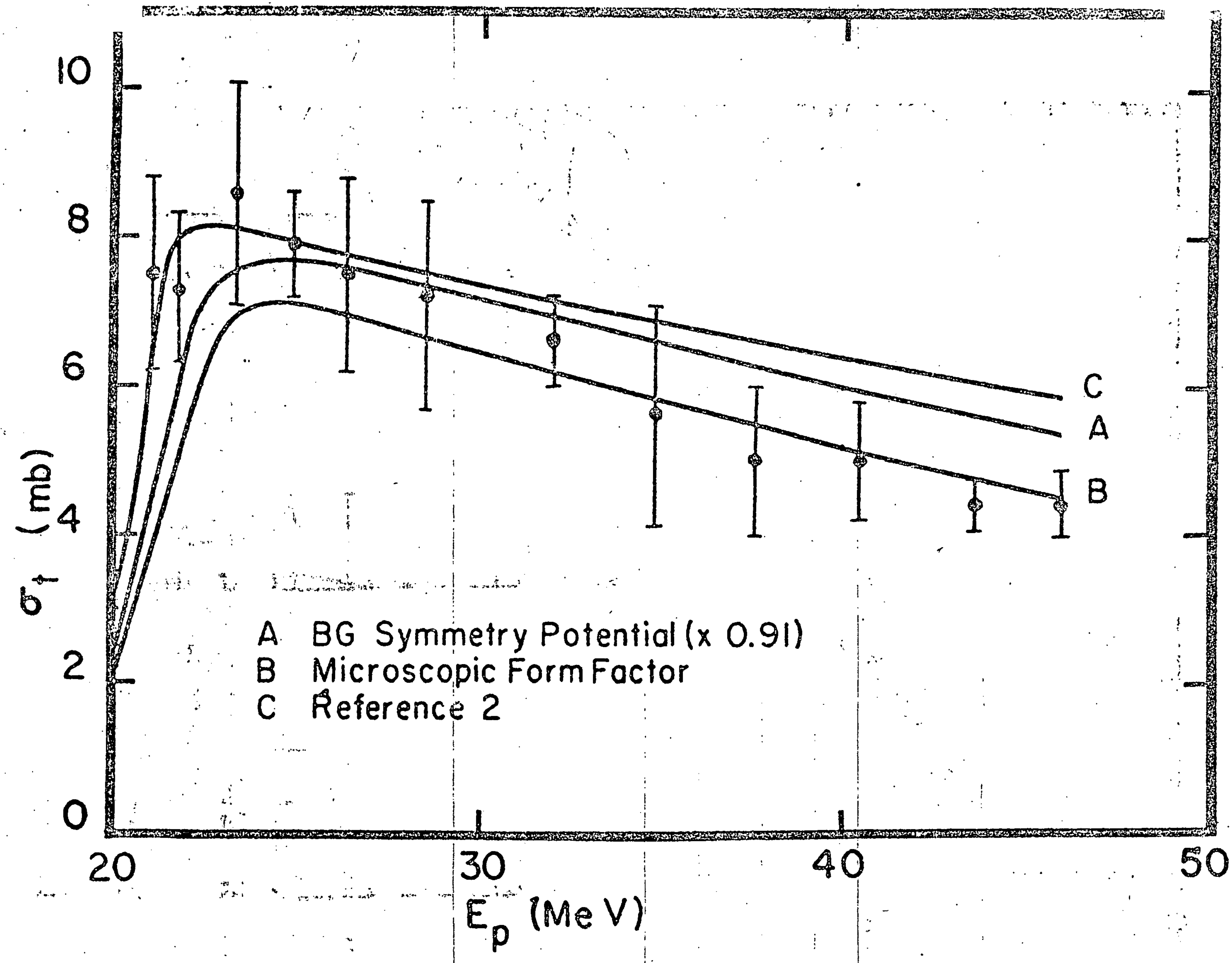
Figure Captions

Fig. 1 $^{208}Pb(p,n)^{208}Bi$ quasi-elastic angular distributions for E_p=26. Form factors described in text.

Fig. 2 $^{208}Pb(p,n)^{208}Bi$ excitation functions. Form factors described in text. FP neutron optical potentials for $E_p > 35$ MeV and BG neutron parameters for $E_p > 35$ MeV.



208Pb(p,n)208Bi 25.85 MeV
10+1
10+0
10-1
10-2
dσ/dΩ (mb/sr)
A
B
C
Form Factors
A BG symmetry potential
B microscopic
C reference 2
0
20
40
60
80
100
120
140
160
Θc.M. (degrees)



10
8
6
4
2
0
σt (mb)
C
A
B
A BG Symmetry Potential (x 0.91)
B Microscopic Form Factor
C Reference 2
20
30
40
50
Ep (Me V)