EXCHANGE EFFECTS IN STRIPPING REACTIONS

V. G. NEUDACHIN

Scientific Research Institute of Nuclear Physics, Moscow State University

Submitted to JETP editor May 9, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 1165-1170 (November, 1958)

Formulas for the differential cross sections of the stripping reactions (d, p) and (d, n) have been obtained in the Born approximation, with inclusion of effects of the antisymmetry of the total wave function. The most important case, that of the shell configurations j^{n-1} for the initial nucleus and j^n for the final nucleus, has been considered.

1. GENERAL THEORY

It has been shown in a number of papers that in particular cases of calculations of stripping reaction cross-sections the antisymmetrization of the total wave function can affect the results of the calculations to an important extent.[1] Calculations on stripping reactions with inclusion of the antisymmetrization have not been carried out, however, unless one counts the work of French, which is of a preliminary nature.

We shall use the results of the general theory of scattering.[2,3] We first carry through a treatment without antisymmetrization. We assign the numbers 0 and 1 to the proton and neutron in the deuteron; V(01) is the interaction between them. The interaction of the proton with the other nucleons of the nucleus is described by an averaged potential $V(0\xi)$, taken, for example, from the optical model. Then the wave function is determined from the equation

$$\Psi^{(+)} = \Phi + (1/a^{(\pm)}) V(01)\Phi, \quad a^{(\pm)} = E \pm i\varepsilon - H, \qquad (1)$$

where H is the total Hamiltonian of the system, and Φ is the wave function of the initial state [reaction (p, d)].

The antisymmetrization is performed by the application of an operator A (whose concrete form will be given below):

$$\overline{\Psi}^{(+)} = A\Psi^{(+)} = A\Phi + (1/a^{(\pm)}) AV\Phi. \qquad (2)$$

To obtain the expression for the reaction amplitude in the Born approximation, we replace 1/a by 1/a′(01), using the fact that[3]

$$1/a = \{1/a'(01)\}[1 + \{H'(01)/a\}],$$

where a′(01) is the Green's function of the final system,[2] and $H_{fin} = H - H'(01)$ is its Hamiltonian.

The reaction amplitude is given by the second term in Eq. (2), that is,

$$AV\Phi / a'(01). \qquad (3)$$

Thus our task reduces to the calculation, in Born approximation with distorted waves for the protons and deuterons, of the matrix element

$$\int \Psi^*_{\text{fin}}(2, 3, \ldots, n)\Psi^*_{\mathbf{k}_d}(0,1) AV\Psi_{\text{int}}(1, 2\ldots n) \times \Psi_{\mathbf{k}_p}(0)\, d\mathbf{r}_0 \ldots d\mathbf{r}_n, \qquad (4)$$

where Ψ_{fin} is the wave function of the final nucleus, Ψ_{init} is that of the initial nucleus, $\Psi_{\mathbf{K}_p}$ is the wave function of the proton in the field of the initial nucleus, and $\Psi_{\mathbf{K}_d}$ is that of the deuteron. The antisymmetrization operator A is defined in the following way:

$$AV\Psi_{\text{int}}(1, 2\ldots n)\Psi_{\mathbf{k}_p}(0) = \frac{1}{\sqrt{n+1}}\sum_{i \neq j}(-1)^{n+1-i} V(i, j) \times \Psi_{\text{int}}(0, 1\ldots i-1, i+1, \ldots n)\Psi_{\mathbf{k}_p}(i). \qquad (5)$$

The normalization factor in this case is found from the requirement of conservation of flux. The antisymmetrization procedure used in Eq. (5) was indicated by Racah in reference 4, where the antisymmetrization was carried out for the wave function of the shell configuration $l^n l'$.

2. CALCULATION WITH WAVE FUNCTIONS OF THE SHELL THEORY

We shall suppose that

$$\Psi_{\text{int}} = |j^n \alpha_1\rangle, \quad \Psi_{\text{fin}} = |j^{n-1}\alpha_2\rangle,$$

where α is the set of quantum numbers necessary for unique specification of a state. Using Racah's technique,[4,5] with the expression (5) for the operator A, we work out the matrix element (4):

$$
\begin{aligned}
&I = 2I_1 + (n-1)\,2I_2 + 2(n-1)(n-2)\,I_3;\\
&I_1 \sim \langle \mathbf{k}_d S_d (12) \,|\, V(12) \,|\, j(1)\, \mathbf{k}_p s_p (2)\rangle;\\
&I_2 \sim \sum_{\alpha_3\alpha_4} \langle \mathbf{k}_d S_d (12),\; j(3) \,|\, V(13) \,|\; j^2\alpha_4 (12)\, \mathbf{k}_p s_p (3)\rangle\\
&\qquad \times \langle j^n\alpha_1 \,|\, j^{n-2}\alpha_3;\; j^2\alpha_4\rangle \langle j^{n-1}\alpha_2 \,|\, j^{n-2}\alpha_3\rangle;\\
&I_3 \sim \sum_{\alpha_5\alpha_6\alpha_7\alpha_8} \langle j^2\alpha_8 (12) \,|\, V(12) \,|\, j(1)\, \mathbf{k}_p s_p (2)\rangle \langle \mathbf{k}_d S_d (34) \,|\, j^2\alpha_6 (34)\rangle\\
&\qquad \times \langle j^n \alpha_1 \,|\, j^{n-2}\alpha_5;\; j^2\alpha_6\rangle \langle j^{n-1}\alpha_2 \,|\, j^{n-3}\alpha_7;\; j^2\alpha_8\rangle \langle j^{n-2}\alpha_5 \,|\, j^{n-3}\alpha_7\rangle.
\end{aligned}
\tag{6}
$$

Here $\langle j^n | j^{n-1}\rangle$ and so on are fractional parentage coefficients. Thus the calculation of the differential cross-section reduces to the calculation of I_1^2, I_2^2, $I_1 I_2$, etc.

In carrying out the sums of products of Clebsch-Gordan coefficients over magnetic quantum numbers we have used the effective graphic method of Levinson.[6] We thus arrive at the following formulas (the expressions for the interference terms are not presented here):

$$
\begin{aligned}
I_1^2 &= \frac{[J_1][S_d]}{4\pi[s]} \left(C^{1/2\,1/2\,0}_{1/2\,-1/2\,0}\right)^2 \left(C^{T_2\tau T_1}_{M_{\tau_2}\,-1/2\,M_{\tau_1}}\right)^2 \\
&\quad\times \langle j^n\alpha_1 \,|\, j^{n-1}\alpha_2\rangle\, D_l^2(\mathbf{k}_p - \mathbf{k}_d),\\
D_l(\mathbf{k}_p - \mathbf{k}_d) &= 4\pi\varphi_l(R)\,[h_l^{(1)}(\varkappa R)]^{-1}\\
&\quad\times \frac{\hbar^2 (8\pi\alpha)^{1/2}}{M} \int_R^\infty h_l^{(1)}(\varkappa r)\, j_l(|\mathbf{k}_p - \mathbf{k}_d|\, r)\, r^2 dr.
\end{aligned}
\tag{7}
$$

Here α is the reciprocal of the deuteron radius; $\varphi_l(R)$ is the amplitude of the wave function of a bound nucleon at the surface of the nucleus; $h_l^{(1)}(x)$ is the spherical Hankel function of the first kind; $j_l(x)$ is the spherical Bessel function; κ is the imaginary wave number of a bound nucleon; R is the radius of the "edge" of the nucleus; $[J_1] = 2J_1 + 1$, etc.; and $C^{j_1 j_2 j_3}_{m_1 m_2 m_3}$ are Clebsch-Gordan coefficients.

$$
\begin{aligned}
I_2^5 &= (4\pi)^2 [J_1][J_2][j]^3 [l] \left(C^{T_1\tau T_2}_{M\tau_1\,1/2\,M\tau_2}\right)^2 \sum [a][b] \begin{Bmatrix} l & s & j\\ l & s & j\\ L_4 & S_4 & J_4\end{Bmatrix} \sqrt{[S_4][J_4]}\,[L_4][L_0] \langle j^n\alpha_1 \,|\, j^{n-2}\alpha_3;\; j^2\alpha_4\rangle \langle j^{n-1}\alpha_2 \,|\, j^{n-2}\alpha_3\rangle \hat{C}^{LL'a}_{000}\\
&\times \hat{C}^{l_2 l_2' a}_{000} \hat{C}^{lLL_0}_{000} \hat{C}^{lkL_0}_{000} \hat{C}^{kl_2 l}_{000} \begin{Bmatrix} L_4 & l & l\\ k & L_0 & l_2\end{Bmatrix} E_{\mathbf{k}_d\mathbf{k}_p}(l, k, l_2, L) \sqrt{[S_4'][J_4']}\,[L_4'][L_0'] \begin{Bmatrix} l & s & j\\ l & s & j\\ L_4' & S_4' & J_4'\end{Bmatrix} \langle j^n\alpha_1 \,|\, j^{n-2}\alpha_3';\; j^2\alpha_4'\rangle\\
&\times \langle j^{n-1}\alpha_2 \,|\, j^{n-2}\alpha_3'\rangle \hat{C}^{lk'L_0'}_{000} \hat{C}^{lk'L_0'}_{000} \hat{C}^{k'l_2'l}_{000} \begin{Bmatrix} L_4' & l & l\\ k' & L_0' & l_2'\end{Bmatrix} E^*_{\mathbf{k}_d\mathbf{k}_p}(l, k', l_2', L')(-1)^{\rho_{22}} \begin{bmatrix} L_0' & L' & a & l_2'\\ l & L & l_2 & L_4'\\ b & l & L_0 & L_4\end{bmatrix} \begin{Bmatrix} J_4 & L_4 & S_d\\ L_4' & J_4' & b\end{Bmatrix}\\
&\times \begin{Bmatrix} J_3 & J_4 & J_1\\ J_4' & J_3' & b\end{Bmatrix} \begin{Bmatrix} J_3 & j & J_2\\ j & J_3' & b\end{Bmatrix} \begin{Bmatrix} l & j & s\\ j & l & b\end{Bmatrix} P_a(\cos\theta).
\end{aligned}
\tag{8}
$$

Here S_d is the spin of the deuteron, s that of the nucleon; $\rho_{22} = J_1 + J_2 + l + s + l_2 + L + a$; the summation is taken over all indices except l, s, j, S_d, α_1, α_2 [α = (J, T, seniority)]. We also make use of the facts that $S_4 = S_4' = S_d = 1$, $T_4 = T_4' = T_d = 0$, $J_4 + T_4$ is even, $L_4 + S_4 + T_4$ is odd;

$$\begin{Bmatrix} j_1 & j_2 & j_3\\ j_4 & j_5 & j_6\end{Bmatrix} = (-1)^{j_1+j_2+j_4+j_5} W(j_1 j_2 j_5 j_4;\; j_3 j_6),$$

W is a Racah coefficient; $\begin{Bmatrix} j_1 & j_2 & j_3\\ l_1 & l_2 & l_3\\ k_1 & k_2 & k_3\end{Bmatrix}$ is a 9j symbol[7,8];

$\begin{bmatrix} j_1 & j_2 & j_3 & j_4\\ l_1 & l_2 & l_3 & l_4\\ k_1 & k_2 & k_3 & k_4\end{bmatrix}$ is a 12j symbol of the second kind[8];

$$\begin{bmatrix} j_1 & j_2 & j_3 & j_4\\ l_1 & l_2 & l_3 & l_4\\ k_1 & k_2 & k_3 & k_4\end{bmatrix} = \sum_x (-1)^f [x] \begin{Bmatrix} j_1 & k_1 & x\\ k_2 & j_2 & l_1\end{Bmatrix} \begin{Bmatrix} j_2 & k_2 & x\\ k_3 & j_3 & l_2\end{Bmatrix} \begin{Bmatrix} j_3 & k_3 & x\\ k_4 & j_4 & l_3\end{Bmatrix} \begin{Bmatrix} j_4 & k_4 & x\\ k_1 & j_1 & l_4\end{Bmatrix},$$

f is the sum of all the parameters of the 12j symbol;

$$\hat{C}^{l_1 l_2 l_3}_{000} = \sqrt{[l_1][l_2]/4\pi[l_3]}\; C^{l_1 l_2 l_3}_{000};$$

θ is the angle between $\mathbf{k}_d$ and $^1/_2\,\mathbf{k}_d - \mathbf{k}_p$;

$$E_{\mathbf{k}_d,\,\mathbf{k}_p}(l, k, l_2, L) = V_0 i^{l_2 - L} \iint_R^\infty f_k(r_1, r_2)\, j_{l_2}\!\left(\frac{1}{2} k_d r_2\right) j_L\!\left(\left|\frac{1}{2}\mathbf{k}_d - \mathbf{k}_p\right| r_1\right) \varphi_l^2(r_1)\, \varphi_l(r_2)\, r_1^2 r_2^2\, dr_1\, dr_2,$$

where $\varphi_l(r)$ is the radial part of the wave number of a bound nucleon with the orbital angular momentum l; $f_k(r_1, r_2)$ is defined in terms of the internal wave function of the deuteron

$$\chi_d(\mathbf{r}_1-\mathbf{r}_2)=\sum_k f_k(r_1,r_2)[k]P_k(\cos\omega_{12}),$$

in particular[1,9]

$$e^{-\alpha r_{12}}/r_{12}=\alpha\sum_k [k]\, j_k(i\alpha r_1)\, h_k^{(1)}(i\alpha r_2)\, P_k(\cos\omega_{12})$$

for $r_1 < r_2$; $V_0 = 4\pi\hbar^2 M\alpha$ [the interaction potential of the nucleons is taken in the form $V_0\delta(\mathbf{r}_1 - \mathbf{r}_2)$].

$$I_3^2=\frac{1}{4\pi}\left(C^{T_1\tau T_2}_{M_{T_1}{}^{1}\!/_{2} M_{T_2}}\right)^2[J_1][J_2][j][T_1]\sum C^{j^n_{\alpha_1}}_{j^{n-2}\alpha_6;\, j^2\alpha_8}$$
$$\times C^{j^{n-1}\alpha_2}_{j^{n-3}\alpha_7;\, j^2\alpha_5}\, C^{j^{n-2}\alpha_6}_{j^{n-3}\alpha_7}\begin{Bmatrix}T_2 & T_1 & \tau\\ \tau & T_5 & T_7\end{Bmatrix}\begin{Bmatrix}T_2 & T_1 & \tau\\ \tau & T_5' & T_7'\end{Bmatrix}[T_5]^{1/2}[T_5']^{1/2}$$
$$\times(-1)^{2T_1+1+T_7+T_7'}\hat{C}^{l\,l\,L_5}_{000}\hat{C}^{L_5 l\, l_p}_{000}\hat{C}^{l\,l\,L_5'}_{000}\hat{C}^{L_5' l\, l_p'}_{000}$$
$$\times\hat{C}^{l_p l_p' a}_{000}\hat{C}^{L_8 L_8' a}_{000}\sqrt{[J_6][J_6'][J_8][J_8'][J_5][J_5'][S_5][S_5'][l_p][l_p']} \tag{9}$$
$$\times(-1)^{\rho_{33}}\begin{Bmatrix}L_8 & J_8 & S_8\\ J_8' & L_8' & a\end{Bmatrix}\begin{Bmatrix}J_8 & J_6 & J_1\\ J_6' & J_8' & a\end{Bmatrix}\begin{Bmatrix}J_6' & J_2 & b\\ J_5' & j & J_7'\end{Bmatrix}\begin{Bmatrix}J_6 & J_2 & c\\ J_5 & j & J_7\end{Bmatrix}\begin{Bmatrix}j & l & s\\ J_5' & L_5' & S_5'\\ b & l_p' & s\end{Bmatrix}$$
$$\times\begin{Bmatrix}j & l & s\\ J_5 & L_5 & S_5\\ c & l_p & s\end{Bmatrix}\begin{Bmatrix}J_6 & c & J_2\\ b & J_6' & a\end{Bmatrix}\begin{Bmatrix}c & l_p & s\\ l_p' & b & a\end{Bmatrix}P_a(\cos\gamma)A_{\mathbf{k}_d}(l^2,L_8)$$
$$\times A^*_{\mathbf{k}_d}(l^2,L_8')B_{\mathbf{k}_p}(l,l_p)B^*_{\mathbf{k}_p}(l,l_p')+\text{comp. conj.}$$

where

$$A_{\mathbf{k}_d}(l^2,L_8)=4\pi i^{-L_8}\int_R^\infty j_{L_8}(k_dR)Y^*_{L_8,M_8}(\mathbf{R}_d)\chi_d(\mathbf{r})$$
$$\times\Psi_{l^2L_8M_8}(\mathbf{r}_1\mathbf{r}_2)\,d\mathbf{r}_1 d\mathbf{r}_2,\quad \mathbf{R}_d=\frac{\mathbf{r}_1+\mathbf{r}_2}{2},\quad \mathbf{r}=\mathbf{r}_1-\mathbf{r}_2;$$

$$B_{\mathbf{k}_p}(l,l_p)=4\pi i^{l_p}V_0\int_R^\infty \varphi_l^3(r)\, j_{l_p}(k_pr)\,r^2dr;$$

$\rho_{33} = J_1 + J_2 - s + 1 + b + c + J_7 + J_7'$; in the summation we use the facts that $S_8 = S_d = 1$, $T_8 = T_d = 0$, $J_8 + T_8$ is odd, $L_8 + S_8 + T_8$ is odd; γ is the angle between $\mathbf{k}_p$ and $\mathbf{k}_d$.

$$\frac{d\sigma}{d\Omega}=\frac{M_pM_d}{4\pi^2\hbar^4}\frac{k_p}{k_d}\frac{1}{[J_2][S_d]}\frac{n}{2}I^2, \tag{10}$$

for the reaction A(d, p)A + 1.

The calculation of the radial integrals B, D, and E is simple in principle. We can make an estimate of the integrals A if we extend the integration over the entire region and use oscillator wave functions for the bound nucleons, which makes it possible to use a simple transformation to separate the motion of the center of mass of two nucleons from their relative motion.[10] For the integrals B, D, and E it is natural to use as the wave functions of the bound nucleon the functions $h_l^{(1)}(\kappa r)$. They are normalized in the following way:[11] $[\varphi_l(R)/h_l^{(1)}(\kappa R)]\,h_l^{(1)}(\kappa r)$; $\varphi_l(R)$ is the amplitude of the single-particle wave function at the surface of the nucleus. The Wigner limit for the reduced width corresponds to the value of $\varphi_l(R)$ given by:[12] $R^3[\varphi_l(R)]^2/2 = 1$.

The usual theory of stripping involves only one radial integral $D_{\mathbf{k}_d,\mathbf{k}_p}(l)$, and its absolute value does not affect the angular distribution. Use of plane waves in the crudest sort of calculation gives for the particles topping the barrier an increase of the radial integral by a factor of five to seven, in the case of reactions with light nuclei.[11,13] The facts show,[14] however, that the relative values of the absolute cross-sections for cases of capture of nucleons with different values of l are well reproduced by the expression $D^2(l)$.

Our results involve a large number of radial integrals, so that the crudeness with which they are estimated makes the results, generally speaking, rather indefinite. Nevertheless the fact noted above allows us to hope that for each series of integrals the dependences on k, L, l_p, and so on are given correctly, so that in the calculation of angular distributions we can try to confine ourselves to the two unknown constant coefficients of I_2 and I_3, with a crude preliminary estimate of their order of magnitude.

The calculation of the expressions containing spherical functions can be carried out more simply by directing the z axis along one of the momenta, for example $\frac{1}{2}\mathbf{k}_d - \mathbf{k}_p$, or $\mathbf{k}_d$, etc., depending on the particular term.

3. CONCLUDING REMARKS

The cases that are the simplest and most interesting to analyze occur when one or two of the three terms in the expression (6) for the matrix element vanish. If n = 1, there remains only I_1, and we arrive at the usual formulas of the theory of stripping. If n = 2, the term in I_3 vanishes. If we consider the inverse process, the proton is incident on an odd-odd nucleus with two nucleons outside a closed shell. The structure of the expression (6) for the amplitude I_2 shows that I_2 is the reaction amplitude for the process of "knocking out" of a deuteron from the nucleus by the proton, which is itself bound in the final state. I_3^2 corresponds to the process of "heavy particle stripping,"[15,16] although it is not a complete expression for the squared amplitude of this process. In this case the angular distribution will have a maximum in the backward hemisphere. I_2^2 will evidently not have this peculiarity, since the "knocking out" of a particle is as a rule associated with a maximum in the forward part of the angular distribution. This argument agrees qualitatively with the angular distribution[17] of the protons from the reaction $B^{10}(dp)B^{11*}(J^* = \frac{1}{2}-)$, which is mainly due to a term of the type I_2^2. In fact, in a case in which $J_{fin} = J_1$ cannot be obtained by vector composition of $J_{init} = J_2$ and j, $I_1 = 0$, i.e., ordinary "stripping" is "forbidden" in the shell theory. There remain the terms in I_2 and I_3. An example of this latter type occurs in the reaction $B^{10}(n,d)Be^{9*}$ with formation of the Be^9 in the first excited state $J^* = \frac{1}{2}-$.

For the calculation of the cross-section of the reaction $B^{10}(d,p)B^{11*}$ mentioned above, the final formulas must be changed somewhat, since the final nucleus is described by the configuration j^6j', $j = 3/2-$, $j' = 1/2-$.

In conclusion the writer expresses his gratitude to K. A. Ter-Martirosian for a discussion of the statement of the problem.

[1] A. P. French, Phys. Rev. **107**, 1655 (1957). Kammuri, Nakasima, and Takagi, Prog. Theor. Phys. **17**, 306 (1957).

[2] B. A. Lippmann, Phys. Rev. **102**, 264 (1956).

[3] G. Takeda and K. M. Watson, Phys. Rev. **97**, 1336 (1955).

[4] G. Racah, Phys. Rev. **63**, 367 (1943).

[5] G. Racah, Phys. Rev. **62**, 438 (1942). A. R. Edmonds and B. H. Flowers, Proc. Roy. Soc. **A214**, 515 (1952).

[6] I. B. Levinson, Тр. физ.-техн. ин-та АН ЛитССР (Trans. Phys.-Tech. Inst. Acad. Sci. Lithuanian S.S.R.) **2**, 17, 31 (1957); Тр. АН ЛитССР (Trans. Acad. Sci. Lithuanian S.S.R.) **B4**, 3 (1957).

[7] A. de-Shalit, Phys. Rev. **91**, 1479 (1953). Arima, Horie and Tanabe, Prog. Theor. Phys. **11**, 143 (1954). H. Jahn and J. Hope, Phys. Rev. **93**, 318 (1954).

[8] I. B. Levinson and V. V. Vanagas, Оптика и спектроскопия (Optics and Spectroscopy) **2**, 10 (1957).

[9] W. Swiatecki, Proc. Roy. Soc. **A205**, 238 (1951).

[10] I. Talmi, Helv. Phys. Acta **25**, 185 (1952).

[11] W. Tobocman and M. H. Kalos, Phys. Rev. **97**, 132 (1955).

[12] A. M. Lane, Proc. Phys. Soc. **A66**, 977 (1953).

[13] K. Standing, Phys. Rev. **101**, 152 (1956).

[14] J. Holt and T. Marsham, Proc. Phys. Soc. **A66**, 1032 (1953).

[15] T. Fulton and G. E. Owen, Phys. Rev. **108**, 789 (1957).

[16] L. Madansky and G. E. Owen, Phys. Rev. **99**, 1608 (1955).

[17] N. Evans and W. Parkinson, Proc. Phys. Soc. **A67**, 684 (1954).

Translated by W. H. Furry
247

ERRATA TO VOLUME 7

Page	Reads	Should Read
533, title	Nuclear magnetic moments of Sr^{87} and Mg^{95}	Nuclear magnetic moments of Sr^{87}
645 Eq. (1)	$\ldots + \varkappa \sqrt{j_0 (j_0 + 1)}$	$\ldots - \varkappa \sqrt{j_0 (j_0 + 1)}$
647 Eq. (11)	$(L+1) \lvert B_L^- \rvert^2 - L \lvert B_L^+ \rvert^2$	$L(L+1) \left[\lvert B_L^- \rvert^2 - \lvert B_L^+ \rvert^2 \right]$
894 Eq. (12)	$\varepsilon_{11} = 1 - \sum \frac{\cdots}{\sqrt{\pi/\mu}}$	$\varepsilon_{11} = 1 - \sum \frac{\cdots}{\sqrt{\pi}\,\mu}$
897 Eq. (45)	$\sqrt{\pi/2}$	$\sqrt{\pi/8}$
979 Table II, heading	$\lvert E_\gamma > 50$ **Mev** $\lvert E_\gamma > 50$ **Mev**	$\lvert E_\gamma < 50$ **Mev** $\lvert E_\gamma > 50$ **Mev**
1023 Figure caption		a) $\omega < \omega_H$, b) $\omega > \omega_H$
1123 Eq. (2)	$\Gamma = \mu_2/\mu_1$	$\Gamma = \mu_2/\mu_1,\ \mu_\perp = (\mu_1^2 - \mu_2^2)/\mu_1$

ERRATA TO VOLUME 8

Page	Reads	Should Read
375 Figure caption	a) positrons of energy up to 0.4 ϵ, b) positrons of energy up to 0.3 ϵ.	a) positrons of energy up to 0.3 ϵ, b) positrons of energy up to 0.4 ϵ.
816 Beginning of Eq. (8)	$I_2^5 = (4\pi)^2 \ldots$	$I_2^2 = (4\pi)^5 \ldots$