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INELASTIC SCATTERING OF ANTIPROTONS BY ^{12}C

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A B S T R A C T

Inelastic scattering of antiprotons ($p_{\text{lab}} = 600 \text{ MeV}/c$) by ^{12}C leading to the excitation of the three lowest normal parity $T = 0$ levels is studied in the framework of the Glauber model and distorted wave impulse approximation. The transition densities obtained from fit to the electron scattering data and the elementary two-body amplitudes are used in the calculation. Distortion effects are taken into account by the elastic $\bar{p}$ -nucleus scattering amplitudes. The results are seen to be in fairly good agreement with the available experimental data.

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1. - INTRODUCTION

With the advent of LEAR facility at CERN, good quality of experimental data on low and intermediate energy antiproton-nucleus scattering have become available. These include measurements (Garreta et al. 1984a, 1984b, Garreta 1985) of angular distributions for $\bar{p}$ -A elastic and inelastic scattering which exhibit diffraction patterns characteristic of a strongly absorbing particle. The inelastic angular distribution for exciting the three lowest normal parity $T = 0$ states in ^{12}C at 4.44 MeV ($J^\pi=2^+$), 7.66 MeV ($J^\pi=0^+$) and at 9.63 MeV ($J^\pi=3^-$) by 600 MeV/c antiprotons have been measured recently (Garreta 1985). Several analyses (both microscopic and macroscopic) based on optical potential model and distorted wave approximations (Dover and Millener 1985, Adachi and Ceramb 1985, Lemaire et al. 1986) have been reported and have met with considerable success in reproducing the data. The success of the impulse approximation indicates that medium corrections become unimportant because the inelastic scattering is localized in the nuclear surface due to strong annihilation of antiprotons into meson channels.

In the present work, we have analyzed the inelastic antiproton scattering by ^{12}C within the framework of the Glauber model (Glauber 1959) which has been shown (Mahalanabis 1986, Dalkarov et al. 1984) to be successful in reproducing the $\bar{p}$ - ^{12}C elastic scattering data at these energies and have been used widely for describing the hadron nucleus interaction. The importance of the Glauber theory lies in its simplicity, transparency and more direct connections to observables compared to standard optical model approaches. Moreover, it has been shown numerically (Lee and McManus, 1967) that even at 156 MeV inelastic proton scattering there is, in fact, little merit in resolving the optical potential exactly rather than using the eikonal approximation. Hence, it is worth while to study the inelastic scattering of antiprotons by using the parameter-free Glauber model and to compare them with the experimental data and microscopic optical model calculations.

We use the elementary two-body amplitudes and the inelastic transition form factors as basic input in the calculation. The former is taken from the recent analysis (Brückner et al. 1985) of the $\bar{p}$ -N scattering data and the later is taken from the fit to the experimental electron scattering data (Saudinos and Wilkin 1974, Crannell 1966). The same transition densities also reproduced the measured cross-sections for inelastic transitions in ^{12}C induced by pions and kaons (Toyama and Sakamoto 1981, Sakamoto et al. 1982) fairly well. In the next section, a brief outline of the formalism is given and the results are presented

in Section 3 together with discussions. The last section contains the conclusions.

2. - THEORY

In the Glauber model, the transition amplitude for scattering of a particle by a nucleus of mass number A is written in the impact parameter representation as

$$F_{fi}(\vec{q}) = \frac{iK}{2\pi} \int e^{i\vec{q} \cdot \vec{b}} d^2\vec{b} \langle \psi_f | \Gamma_A(\vec{b}, \vec{s}_1, \vec{s}_2, \dots, \vec{s}_A) | \psi_i \rangle \quad (1)$$

where K is the wave number of the incident particle, $\vec{q}$ is the momentum transfer, ψ_i, ψ_f denote the initial and final states of the target, $\vec{s}_j$ is the projection of the radius vector $\vec{r}_j$ of the j^{th} nucleon on a plane perpendicular to the direction of $\vec{k}$ which is chosen along the z axis. The profile function $\Gamma_A(\vec{b}, \vec{s}_1, \vec{s}_2, \dots, \vec{s}_A)$ is written as

$$\Gamma_A(\vec{b}, \vec{s}_1, \vec{s}_2, \dots, \vec{s}_A) = 1 - \prod_{j=1}^A [1 - \Gamma_j(\vec{b} - \vec{s}_j)] \quad (2)$$

with

$$\Gamma_j(\vec{b}) = \frac{1}{2\pi iK} \int e^{-i\vec{q}' \cdot \vec{b}} f_j(\vec{q}') d^2\vec{q}' \quad (3)$$

where $\vec{k}$ is the two-body centre-of-mass momentum and $f_j(\vec{q})$ is the amplitude for elastic scattering of the j^{th} target nucleon with the incident particle.

The calculation of transition amplitude [Eq. (1)] requires the knowledge of the nuclear wave functions. The use of model wave functions can be avoided in the single inelastic collision (SIC) approximation (Karapetjan 1973) by using the experimental transition form factors obtained from electron scattering data. The expression for the inelastic transition amplitude in the SIC has the form

$$F_{fi}(\vec{q}) = A f(\vec{q}) S_{fi}(\vec{q}) - \frac{A}{2\pi iK} \int f(\vec{q}') S_{fi}(\vec{q}') \cdot F_{ii}(\vec{q}'') \delta(\vec{q} - \vec{q}' - \vec{q}'') d^2\vec{q}' d^2\vec{q}'' \quad (4)$$

where $F_{ii}(q)$ is the elastic scattering amplitude for the (A-1) nucleons and $S_{fi}(q)$ is the inelastic transition form factor given by

$$S_{fi}(\vec{q}) = \left[\frac{4\pi}{2J+1} \right]^{1/2} Y_{JM}^*(\hat{q}) S_J(q) \quad (5)$$

and $S_J(q)$ is the reduced form factor which is measured by electron scattering experiments (Crannell 1966). Assuming the Born approximation to be valid, the reduced form factor is fitted to the electron scattering data in the form (Saudinos and Wilkin 1974)

$$S_J(q) = q^n (B + Cq^2) e^{-Dq^2} \quad (6)$$

where $n = 2, 3$ for the 2^+ and 3^- transitions and $n = 2$ for the 0^+ transition. The best fitted values for the transition form factors are given in the Table.

The two-body amplitude is taken to be spin-independent and is parametrized in the form

$$f_j(q) = \frac{k\sigma}{4\pi} (i + \rho) e^{-\beta^2 q^2/2} \quad (7)$$

in terms of total cross-section σ , the relative real part ρ and the slope parameter β^2 for the $\bar{N}$ -N interactions. These are taken from the analysis of $\bar{p}$ -p scattering data (Brückner et al. 1985). In the present calculation we have used the values of parameters of the scattering amplitudes from the $\bar{p}$ -p scattering data. These are taken as $\sigma = 140.5$ mb, $\rho = 0.25$ and $\beta^2 = 19.4$ (GeV/c) $^{-2}$. As no experimental data exist for the $\bar{p}$ -n scattering we have used the same values for the $\bar{p}$ -p and $\bar{p}$ -n scattering amplitudes.

The form (4) for the inelastic scattering amplitude for the isoscalar transition in the distorted wave impulse approximation (DWIA) is thus expressed in terms of the elementary two-body amplitude $f_j(q)$ and the electromagnetic form factor $S_J(q)$ and the elastic scattering amplitude $F_{ii}(q)$ for the (A-1) nucleons. The first term gives the plane wave results (PWIA) and the last term introduces the distortion effects due to the (A-1) nucleons of the nucleus. Further, for a transition from an initial state $J_i = (0,0)$ to a final state $J_f = (J,M)$, the scattering amplitude vanishes for odd values of (J+M). The cross-sections are obtained by the incoherent sum of the amplitudes for even values of (J+M) only.

The inelastic scattering amplitude, Eq. (4), was evaluated using the values of the parameters taken from the Table. The elastic scattering amplitude $F_{ii}(q)$ for the (A-1) nucleons was obtained using the Glauber model which provides a fairly good description of the elastic $\bar{p}$ - ^{12}C scattering data at 180 MeV

(Mahalanabis 1986). The value of the oscillator length parameter was chosen as 1.62 fm. The centre-of-mass correction was also introduced by multiplying the amplitude with $\exp(q^2 b^2 / 4A)$ as in the elastic scattering case.

3. - RESULTS AND DISCUSSIONS

The results of our calculations are displayed in Figs. 1 to 3 together with the experimental data (Garreta et al. 1984b, 1985). In general, the results of the fit are quite good in reproducing the cross-sections both in shape and magnitude for the 2^+ and the 0^+ states, but for the transition to the 3^- state, discrepancy exists at large momentum transfers where the theory overestimates the cross-sections considerably.

The shape of the angular distribution can be explained from the study of the inelastic amplitude, Eq. (4). At small momentum transfers the cross-section is very sensitive to the form factor $S_J(q)$ but the background term which gives contribution at this value shows up. For small q values, the contribution due to the last term vanishes for $M \neq 0$, whereas this remains finite for $M = 0$. The 2^+ and the 0^+ states get contributions from the $M = 0$ components (Figs. 1 and 2), which produces the forward peak in the cross-section, whereas this feature is absent in the 3^- state (Fig. 3). At larger q values, the amplitude $F_{ii}(q)$ decreases less rapidly than the transition form factor $S_J(q)$ so one sees mainly oscillations determined by the elastic scattering parameters whose normalization depends on the values of the transition density near its maximum (i.e., near $q' \ll q$). Thus, the forward peak and the shape of the inelastic distributions is reproduced in the present formulation.

For the 2^+ state (Fig. 2), the shape and magnitude of the angular distribution are fairly well reproduced except at the position of the minima. The experimental minima appear to be sharper compared to the theoretical ones. The error bars on the experimental points are, however, quite large at these angles. The results are comparable to the microscopic optical model calculations where large basis shell-model wave functions are needed to reproduce the data (Dover and Millener 1985, Adachi and Geramb 1985).

For the 0^+ state (Fig. 2), the theoretical prediction shows a strong oscillatory structure and the agreement with the few data points is quite good; the position of the first diffraction minimum is much better reproduced compared to the microscopic calculations (Geramb 1985) which predict the position of the

first minimum at a slightly larger value of the scattering angle. However, the diffraction minimum is deeper compared to the experimental one.

For the 3^- state (Fig. 3), although we observe a good qualitative agreement with the experimental data, the calculated cross-sections overestimate the later around the positions of the maxima. At the first maximum, this is around 10-15% whereas at the second maximum there is a factor of two discrepancies between the theory and the experimental values. However, the slopes are well reproduced and the discrepancy tends to disappear at these regions. It may be noted that quite large error bars exist on the experimental points beyond 30° scattering angles. This feature is also observed in the microscopic optical model calculations (Dover and Millener 1985, Adachi and Geramb 1985).

The analysis of the inelastic proton scattering data (Saudinos and Wilkin 1974, Gustafsson and Lambert 1978) also showed a discrepancy at larger angles for this state which may be due to some details of the target's nuclear structure property which is not properly accounted for in the employed transition density, or it may lie in the dispersive effects arising from the coupling of this relatively high lying state with the other excited states of the target.

4. - CONCLUSIONS

We conclude that the predictions of the Glauber model in the distorted wave approximation (DWIA) together with the experimental transition densities fitted to the electron scattering data reproduce the inelastic $\bar{p}$ - ^{12}C scattering data fairly well in shape and magnitude. It is also worth mentioning that discrepancy occurs for momentum transfers at which the quality of the transition densities cannot be assessed from electron scattering data. The distortion effects are important for describing the transitions, in particular, the shape of the inelastic angular distribution. The forward region measurements are important which would justify the validity of the distorted wave calculation within the present framework.

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E (MeV)	J^π	n	B	C	D
			fm ⁿ	fm ⁴	fm ²
4.44	2 ⁺	2	0.25	-0.0312	0.57
7.65	0 ⁺	2	0.167		0.99
9.63	3 ⁻	3	0.134		0.77

Table - Parameters for the form factors for the three
T = 0 low-lying normal parity levels in ¹²C
obtained from fit to the electron scattering
data (Saudinos and Wilkin 1974).

REFERENCES

- Adachi S. and Geramb V.G., 1985 "Medium Energy Nucleon and Antinucleon Scattering", Ed. Geramb H.V. (Springer Lecture Notes in Phys. 243) p. 323.
- Brückner W. et al., 1985, Phys.Lett. 158B 180.
- Crannell H., 1966, Phys.Rev. 148 1107.
- Dalkarov O.D. and Karmanov V.A., 1984, Phys.Lett. 147B 1.
- Dover C. and Millener D.J., 1985, "Antinucleon and Nucleon-Nucleus Interaction", Eds. Walker G.E. et al. (Plenum Press) p. 25.
- Garreta G. et al., 1984a, Phys.Lett. 135B 266, E 139B.
- Garreta G. et al., 1984b, Phys.Lett. 149B 64.
- Garreta D., 1985 "Physics with Antiprotons at LEAR in the ACOL Era", Ed. Gastaldi U. et al. (Editions Frontières) p. 599, and private communications.
- Geramb H.V., 1985 "Physics with Antiprotons at LEAR in the ACOL Era", Ed. Gastaldi U. et al. (Editions Frontières) p. 531.
- Glauber R.J., 1959 "Lectures in Theoretical Physics", Vol. I, Ed. Brittin W.E. and Dunham L.H. (Boulder, Interscience Publishers, New York) p. 414.
- Gustaffson C. and Lambert E., 1978, Ann.Phys. 111 304.
- Lee H.K. and McManus H., 1967, Phys.Rev. 161 1087.
- Lemaire M.C. et al., 1986, Nucl.Phys. A456 557.
- Mahalanabis J., 1986, CERN Preprint TH. 4429, and to be published.
- Karapetjan V.V., Mileev V.N. and Titarenko N.N., 1973, Nucl.Phys. A203 561.
- Sakamoto Y., Hatsuda Y. and Toyama F.M., 1982, Phys.Rev. C25 2695.
- Saudinos J. and Wilkin C., 1974, Ann.Rev.Nucl.Sc. 21 341.
- Toyama F.M. and Sakamoto Y., 1981, Lett. Nuovo Cimento 30 97.

FIGURE CAPTIONS

Fig. 1 The angular distribution for the excitation of the 2^+ state at 4.44 MeV in ^{12}C by 600 MeV/c antiprotons are shown together with the experimental data. The contributions due to the $M = 0$ and $M = 2$ are shown separately (dashed and dash-dotted) curves. The full line shows the total contribution for the cross-sections.

Fig. 2 The angular distribution for excitation of the 0^+ state at 7.65 MeV in ^{12}C by 600 MeV/c antiprotons are shown together with the experimental data.

Fig. 3 The angular distribution for excitation of the 3-state at 9.63 MeV in ^{12}C by 600 MeV/c antiprotons are shown together with the experimental data. The contributions due to the $M = 1$ and $M = 3$ components are shown separately (dash-dotted and dashed lines, respectively): The solid line represents the total contribution.

- Figure 1 -

- Figure 2 -

- Figure 3 -