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Abstract

The elastic scattering of Kaons and antiprotons from several nuclei is studied in the framework of the generalized diffraction model due to Frahn and Venter. The systematics of reaction cross section and the standard nuclear radius, as given by the model, are discussed. The parameters obtained from the elastic scattering analyses are used, without any adjustment, to reproduce some inelastic scattering angular distributions and the corresponding deformation parameters are determined.

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1. Introduction

The angular distribution of Kaons and antiproton-nucleus elastic scattering shows pronounced diffractive structure, characteristic of strongly absorbing particles. The K^- meson with strangeness S = -1 forms resonances with nucleons in the region 0 to 1 GeV; while K^+ meson with S = + 1 interacts with nucleons weakly without making any well-established resonances [1]. For the antiproton-nucleus interaction, this diffractive pattern clearly originates from strong antiproton-nucleus interaction. All these can, therefore, be suitable to be described as diffraction phenomena to a first approximation. This is indeed commensurate with the strong absorption model (SAM) of Frahn and Venter [2].

The paper deals with SAM studies of the elastic scattering of Kaons and antiprotons from several nuclei and the parameters so extracted are used in the analyses of some inelastic scattering data leading to collective excitation. The Kaons-nucleus experimental data are taken from refs. [1,3]. The antiproton-nucleus scattering data from ^{12}C, ^{27}Al and ^{64}Cu nuclei have been taken from ref. [4], where the authors have measured absorption cross section and derived antiproton-nucleus optical potential.

2. The SAM mathematical formalism

The strong absorption model has been enunciated by Frahn and Venter [2] following the generalization of the earlier diffraction models. This model is an alternate approach for an optical model to scattering phenomena where the absorption phenomena dominate and the model lies in the intermediate position between the dispersion theory at high energy and the phase shift analysis at low energy. The scattering function η_ℓ is directly parameterized in terms of angular momentum t =(ℓ + ½) and has the suitable form when written in real and imaginary parts as follows:

$$\mathrm{Re}\,\eta_\ell = g(t)$$

$$\mathrm{Im}\,\eta_\ell = \mu\frac{dg(t)}{dt} \qquad (1)$$

The g(t)'s are continuously differentiable functions of the angular momentum, whose first derivatives are symmetric and peaked at T. It is a function of critical angular momentum $T^{\pm}$ (= L ± 1/2) and rounding parameter $\Delta^{\pm}$ in the ℓ - space and its derivatives should have simple Fourier transform. The parameter $\mu^{\pm}$ is associated with the real nuclear phase shift. A closed form expression is attained involving the parameters T, Δ and μ for the differential cross section for elastic scattering. The first two parameters are concerned respectively to the interaction radius R and surface diffuseness d. The standard nuclear radius r_0 is obtained from the interaction radius R. The total reaction cross section can be calculated from the relation:

$$\sigma_r = \pi/k^2\sum_{\ell=0}^{\infty}(2\ell+1)(1-|\eta_\ell|^2)$$

which becomes in terms of T, Δ and μ

$$\sigma_r = \pi T^2 / K^2 [1 + 2\Delta / T + \pi^2 / 3(\Delta / T)^2 - 1/3(\mu / \Delta)^2 \Delta / T]$$

In the strong absorption situation, the elastic scattering formalism discussed so far can be extended to include inelastic scattering leading to collective states. Potgieter and Frahn [5] have obtained a closed form expression for the inelastic scattering amplitude involving the first derivative of the elastic scattering amplitude following the pioneering work of Austern and Blair [6]. The input parameters to describe inelastic scattering are T, Δ and μ, which are all fixed from the elastic scattering analyses. The normalization constant of the theory to experiment is the only free parameter whence the deformation parameters β_L of multiple excitations L are calculated.

3. Results and discussion

3.1. *Elastic scattering.* The angular distribution data for the elastic scattering of Kaons and antiprotons from ^{12}C, ^{27}Al, ^{40}Ca and ^{64}Cu are analyzed in the present work. The best-fit parameters extracted from the study of the elastic scattering are summarized in tables I and II and the corresponding theoretical fits to the experimental data are shown in figs.1- 8.

Table I. The SAM parameters for Kaons.

Projectile + Nucleus	Energy (MeV)	SAM parameters				Derived quantities				
		T	Δ	μ	$\mu / 4\Delta$	R (fm)	d (fm)	r_0 (fm)	σ_r (mb)	$\sigma_r / \pi R^2$
$K^+ + ^{12}C$	446	9.1	2.5	0.50	0.05	2.85	0.76	0.92	453	1.78
$K^- + ^{12}C$	446	8.75	2.0	0.70	0.08	2.71	0.623	0.88	378	1.63
$K^+ + ^{40}Ca$	446	14.0	2.4	0.50	0.05	4.67	0.73	1.00	810	1.42
$K^- + ^{40}Ca$	446	13.7	1.8	0.50	0.07	4.20	0.55	1.00	737	1.33

Table II. The SAM parameters for antiprotons.

Projectile +	Energy (MeV)		SAM parameters				Derived quantities		
Nucleus		T	Δ	μ	$\mu/4\Delta$ (fm)	R (fm)	d (fm)	r_0	$\sigma_r/\pi R^2$
$\bar{p}+{}^{12}C$	109.34	7.5	0.9	0.9	0.25	3.60	0.43	1.01	1.01
$\bar{p}+{}^{12}C$	145.29	8.6	1.0	1.0	0.25	3.50	0.411	1.26	1.06
$\bar{p}+{}^{12}C$	187.44	9.7	0.9	0.5	0.14	3.48	0.326	1.22	1.06
$\bar{p}+{}^{12}C$	238.95	9.7	2.0	1.35	0.17	3.09	0.64	1.54	0.94
$\bar{p}+{}^{12}C$	281.22	10.5	2.1	1.5	0.18	3.08	0.62	1.51	0.94
$\bar{p}+{}^{12}C$	347.4	11.6	2.0	1.8	0.225	3.069	0.53	1.41	0.94
$\bar{p}+{}^{27}Al$	112.93	10.75	0.8	0.70	0.22	4.71	0.357	1.18	1.19
$\bar{p}+{}^{27}Al$	148.61	11.80	1.2	0.80	0.17	4.52	0.466	1.13	1.26
$\bar{p}+{}^{27}Al$	189.66	13.20	0.6	0.90	0.375	4.49	0.207	1.12	1.09
$\bar{p}+{}^{27}Al$	241.37	14.50	1.15	1.1	0.24	4.47	0.351	1.12	1.13
$\bar{p}+{}^{27}Al$	283.15	15.70	0.95	1.0	0.263	4.39	0.268	1.1	1.13
$\bar{p}+{}^{27}Al$	348.79	17.20	0.95	1.0	0.263	4.34	0.241	1.1	1.12
$\bar{p}+{}^{64}Cu$	112.03	14.00	0.70	1.0	0.56	5.96	0.307	1.19	1.142
$\bar{p}+{}^{64}Cu$	147.80	15.75	0.70	0.80	0.29	5.87	0.2863	1.175	1.138
$\bar{p}+{}^{64}Cu$	189.66	17.75	0.80	0.80	0.25	5.78	0.27	1.16	1.125
$\bar{p}+{}^{64}Cu$	240.77	19.50	0.90	0.80	0.22	5.75	0.27	1.15	1.12
$\bar{p}+{}^{64}Cu$	283.15	21.00	0.95	0.85	0.224	5.72	0.262	1.144	1.114
$\bar{p}+{}^{64}Cu$	348.7	23.00	1.0	1.0	0.25	5.65	0.249	1.132	1.102

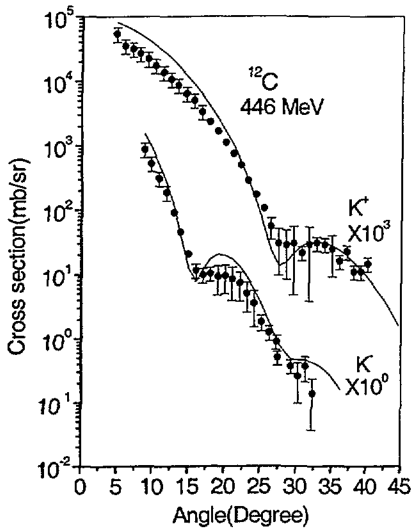

Fig. 1.-SAM fit to the elastic scattering data for ^{12}C.

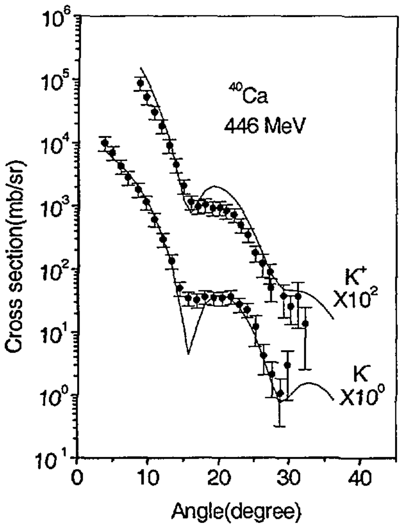

Fig. 2.- SAM fit to the elastic scattering data for ^{40}Ca.

The cross section data at most of the beam energies are limited only to forward angles ($\theta < 20^0$ or so except in few cases in K^+-^{12}C and K^+ -^{40}Ca interaction where the angle extends up to ~ 40^0) and have in some cases a lot of spread. The diffractive maxima and minima increase as both target mass and the beam energy increase (as in cases like ^{27}Al and ^{64}Cu from beam energy 148 MeV onward). Uncertainties in the values of T and Δ are about 10% and that for μ is about 20%. μ is not a very sensitive parameter. An increase in the μ-values raises the cross section values at the minima affecting little on the cross section values elsewhere. It is to be noted that the SAM parameters are uniquely given in the sense that no other combination of the parameter values other than the ones shown in the tables I and II could be obtained giving minimum in the χ^2 value. On the hand, the real depth of the antiproton optical model potential is not well defined. Ambiguities in the optical model potentials of the antiprotons scattering from ^{12}C, ^{40}Ca and ^{208}Pb yield a number of real depths for each nucleus over the range 50- 200 MeV that gave almost identical χ^2 values [7].

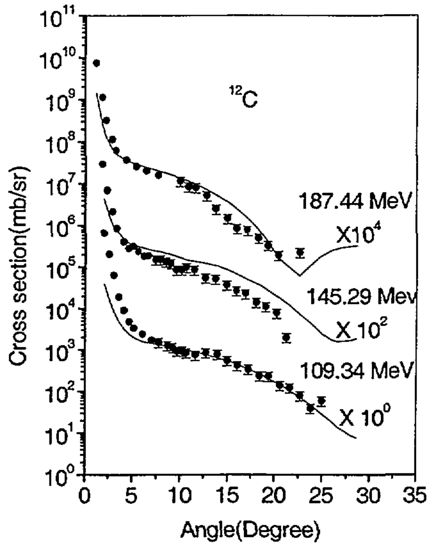

Fig. 3 -SAM fit to the elastic scattering data for ^{12}C

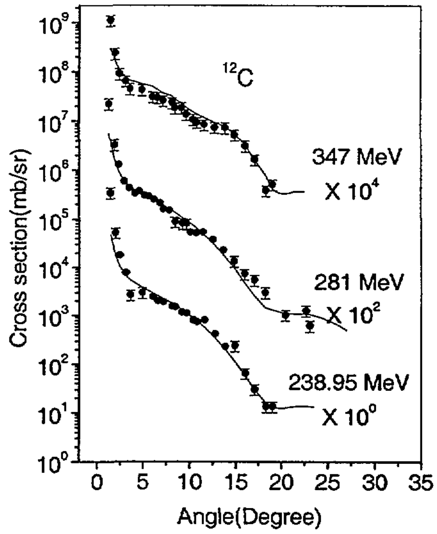

Fig 4.-SAM fit to the elastic scattering data for ^{12}C.

The quality of reproduction of elastic scattering of Kaons from ^{12}C and ^{40}Ca by the model SAM is better than the Glauber model [1]. That the K^+ meson is less absorptive than the K^- meson gets verified through the present analysis. K^+ meson yields a higher interaction radius than the K^- meson (table I) substantiating the fact that K^+ meson is less absorptive than K^- meson. We point out other important aspects of the success of the present calculation that this supports the assertion that 'K^- N interaction is stronger than the K^+N one and hence cross section for the K^--nucleus elastic and inelastic scattering are larger compared to those for the K^+–nucleus scattering'. In other words, reaction cross section for K^+ + ^{12}C interaction should be higher than for K^- +^{12} C interaction. This is supported by the present analyses. The same holds for K^+ + ^{40}Ca interaction (table I).

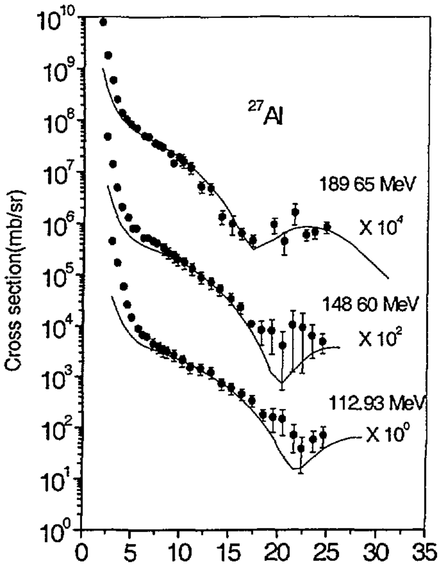

Fig. 5.- SAM fit to the elastic scattering data for ^{27}Al.

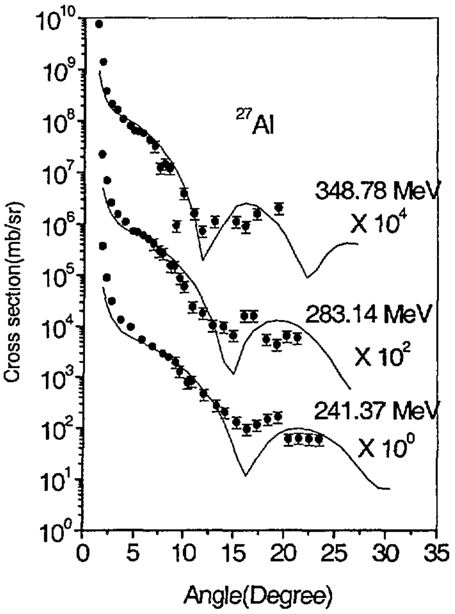

Fig. 6.-SAM fit to the elastic scattering data for ^{27}Al.

The interaction radius (or the so-called strong absorption radius) evidently decreases as the beam energy increases. The standard nuclear radius r_0 from Kaons–nucleus interaction yields a value nearly equaling unity, while antiproton-nucleus interaction results in a value of 1.20 fm--- oft quoted value in the literature. The Kaons scan values over the range 0.55 –0.75 fm for the surface thickness while the antiprotons yield values over the range 0.21- 0.64 fm for the latter. The r_0 and 'd 'are obtainable from T and Δ parameters of the model. Our calculated values of σ_r along with the experimental results and optical model calculations [4] are presented in table III. The mass number dependence of σ_r is also interesting [8]. Clearly the reaction cross section decreases as the beam energy increases, the target mass remaining the same. A close scrutiny of reaction cross section in table III shows an excellent agreement between the SAM predicted values with experimental values and that with optical model calculations. In general, the present model values correspond more to optical model calculation. The quantity $\sigma_r / \pi R^2$ for antiproton-nucleus interaction turns out to be a constant of unity, larger for Kaons-nucleus interaction; which is about 1.5.

Table III. Reaction cross section.

Nucleus	Energy (MeV)	(a)	(b)	(c)
		σ_r (mb)	σ_r (mb)	σ_r (mb)
^{12}C	109.34	494±20	508±20	513
	145.29	486±19	495±20	489
	187.44	466±19	483±20	469
	238.95	461±19	489±20	452
	281.22	452±19	444±20	441
	347.40	417±20	436±20	429
	112.93	830±28	816±30	807
^{27}Al	148.61	809±26	758±30	773
	189.66	690±25	727±30	746
	241.37	710±25	742±30	722
	283.15	683±25	720±30	708
	348.79	659±25	661±30	690
	112.03	1274±35	1220±40	1333
	147.80	1234±35	1268±40	1275
^{64}Cu	189.66	1185±35	1197±40	1231
	240.15	1163±35	1217±40	1193
	283.15	1145±35	1198±40	1170
	348.7	1109±35	1118±40	1143

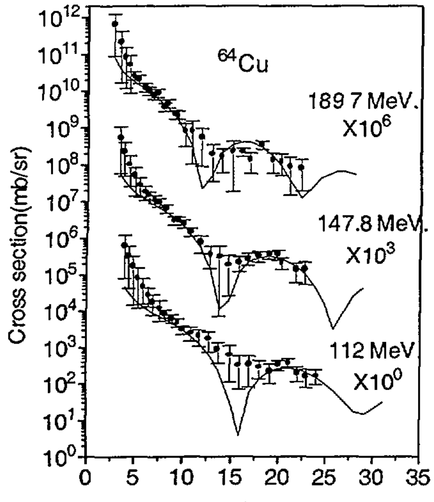

Fig. 7.- SAM fit to the elastic scattering data for ^{64}Cu

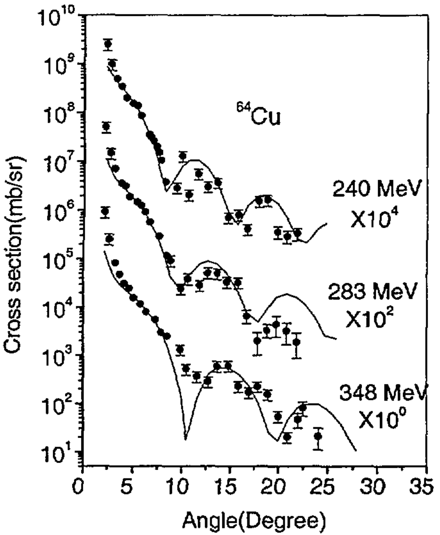

Fig. 8.- SAM fit to the elastic scattering data for ^{64}Cu.

3.2 *Inelastic scattering.* The inelastic scattering of the K^+ and K^- mesons from ^{12}C [1] are analyzed for the transitions to 2^+ and 3 collective states in ^{12}C using the corresponding elastic scattering parameters (table I).

Fits to the experimental data are shown in figs.9-10; the deformation parameter β_L are given in table IV along with values of $B(EL)\uparrow$ measurements, summarized by Raman et al.[9] and Spear[10] respectively for the lowest L=2 and L=3 transitions. Reasonable good fits to the data are obtained and the deformation parameters extracted in this work, though somewhat higher in values, are in good agreement with the above values within allowable uncertainties.

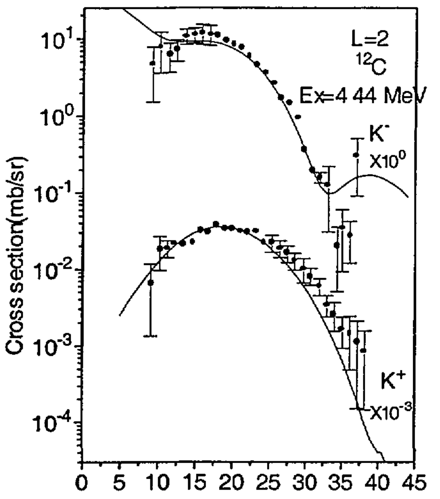

Fig 9. - SAM fit to the inelastic scattering data for the 2_1^+ state in ^{12}C.

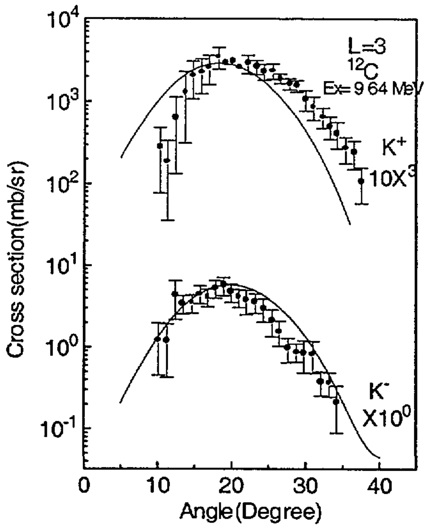

Fig 10 -SAM fit to the inelastic scattering data for the 3_1^- state in ^{12}C .

Table IV. Deformation parameters.

Projectile	Nucleus	J^π	E_x (MeV)	β_L values	
				(a)	
K^+	^{12}C	2^+	4.44	0.67	0.592$^{b)}$
K^-	^{12}C	2^+	4.44	0.60	
K^+	^{12}C	3^-	9.64	0.75	0.60$^{c)}$
K^-	^{12}C	3^-	9.64	0.78	

a) Present work
b) Electromagnetic measurements, ref.[9]
c) Electromagnetic measurements, ref.[10]

4. Conclusion

The generalized diffraction model due to Frahn and Venter renders a reasonably successful and consistent description to the elastic scattering of Kaons and antiprotons from a several target nuclei at different beam energies. The elastic scattering of Kaons is better described by the SAM calculations than by the Glauber model. The present work clearly demonstrates quantitatively a more absorptive nature of K^- meson than K^+ meson in the nucleus and supports the fact that the K^-N interaction is stronger than the K^+ N one. The reaction cross section for antiproton-nucleus at various incident energies agrees very well with experimental results and optical model calculations [4]. Both the strong absorption radius and the reaction cross section decrease with the increase in the beam energy, as expected. The inelastic scattering data for 2^+ and 3^-collective states in ^{12}C are well reproduced by the elastic scattering parameters. The deformation parameters β_L so obtained agree within errors to the corresponding values adopted by Raman et al. [9] and Spear [10]. The SAM is thus an alternate good formalism to other sophisticated formalisms.

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