DEUTERON-NUCLEUS INTERACTIONS AT 10 GeV/c IN BR-2 NUCLEAR EMULSIONS

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Deuteron-nucleus inelastic interactions at 10 GeV/c have been studied in BR-2 nuclear emulsions. Various parameters such as multiplicity, angular distribution, percentage composition of secondary shower particles, stripping and survival probability of deuterons have been determined.

INTRODUCTION

A great deal of experimental work has been reported on proton-nucleus interactions above a proton kinetic energy of 1 GeV. There is still scanty data on multiparticle production in relativistic deuteron-nucleus collisions in nuclear emulsions [1–3]. In the last few years interesting results have been obtained at the JINR proton Synchrophasotron at Dubna [4] by accelerating deuterons up to 11 GeV/c and at Berkeley-Bevalac by accelerating deuterons at relativistic energies [5]. Most of the deuteron collisions have been studied for the sake of stripping reactions [6–8].

Investigation of the general, phenomenological characteristics of deuteron-nucleus interactions seems to be of special interest to both nuclear and elementary-particle physicists. In the present work, in addition to the conventional multiplicity and angular distribution studies, an attempt has been made to estimate the stripping and survival probability for 10 GeV/c deuterons in nuclear emulsions. Because of meagre experimental data, no attempt has been made to correlate it with theoretical predictions [9–11].

EXPERIMENTAL PROCEDURE

BR-2 nuclear emulsion stack, consisting of pellicles of size $20 \times 10 \times 0{\cdot}04\ \mathrm{cm}^3$ was exposed to the 10 GeV/c deuteron beam at the JINR Synchrophasotron (Dubna) in 1974. The average intensity of the extracted mono-energetic beam of deuterons was about 2×10^4 particles/cm^2 with an admixture of protons less than 5%. Ten plates of this stack (D-10) were supplied to us by Professor K. D. Tolstov of JINR, Dubna.

The emulsion plates were scanned at Patiala and Delhi by following the standard method of along the track scanning. Following a total track length of 64·7 metres, 268 interactions were recorded including 12 single prong elastic scatterings. The interactions mean-free paths λ_t and λ_{inel} are $24{\cdot}2 \pm 1{\cdot}5$ cm and $25{\cdot}3 \pm 1{\cdot}6$ cm, respectively. Assuming $A = 47$ for average nucleus of **BR**-2 emulsion, the corresponding values of cross-section σ_t and σ_{inel} are estimated to be 833 ± 52 mb and 796 ± 50 mb, respectively. The mean-free path values obtained by Galstyan et al. [1] for λ_t and λ_{inel} are $22{\cdot}8 \pm 0{\cdot}4$ cm and $25{\cdot}0 \pm 0{\cdot}5$ cm, respectively. The value λ_t obtained by Badyal et al. [3] is $26{\cdot}9 \pm 0{\cdot}8$ cm.

IDENTIFICATION OF SECONDARY SHOWER PARTICLES

The most important information about the primary deuteron-nucleus interactions is obtained by the analysis of relativistic secondary shower particles. The identification of shower prongs produced in inelastic $(d-n)$ interactions is realized by a standard technique of combining scattering measurements with blob density.

Shower prongs with dip angles less than 7° were selected and blobs counted along a length of $1-2$ cm by using an eye-piece ocular scale. For scattering measurements, Fowler's co-ordinate method was used employing cell lengths of 250 and 500 μm on R-4 Koristka microscope. The $p\beta c$ values were calculated using cut-off procedures and applying noise correction obtained from the scattering measurements performed on primary deuteron beam tracks at various depths of each emulsion plate. The statistical errors in $p\beta c$ values are $10-25\%$ and in blob density $2-5\%$.

Shower particles are identified by following the standard criteria [12, 13]. The percentage composition of pions, protons, strange particles and deuterons among the shower secondaries is estimated to be 40 ± 8, 37 ± 8, 13 ± 5 and 10 ± 4 percent, respectively. The relatively large number of protons as compared to pions, can be explained on the basis of stripped protons produced in $d-n$ interactions.

DEUTERON STRIPPING

Stripping of high energy deuterons was first observed at Berkeley by Helmholtz et al. [14]. The process is characterized by the production of a sharp forward peak of nucleons of mean momentum half that of the incident deuteron. The nucleons are emitted in a cone of half angle given by the simple relation [15]:

$$\theta \approx \left(\frac{W_d}{E_d}\right)^{1/2}, \tag{1}$$

where W_d is the deuteron binding energy and E_d is the kinetic energy of the incident deuteron.

The following criteria were used to identify the persisting primary deuterons and protons obtained after stripping of the deuteron:

(a) Shower prongs are selected either from white stars ($n_h = 0$) or from stars with $n_h \leqq 2$. This procedure eliminates deuterons and protons contributed by fragmentation of heavy emulsion nuclei.

(b) The protons obtained from stripping reaction must be emitted in the forward direction with an emission angle of 2° in the laboratory system [eq. (1)]. The persisting deuterons must be emitted in the forward direction with almost negligible deflection.

(c) The emitted protons carry approximately 50% of the primary deuteron momentum in the forward direction and the persisting deuterons, almost the whole of it.

(d) Effect of internal motion of protons inside the deuteron on the stripped proton momentum distribution is ignored.

Shower prongs emitted in the forward cone of half angle 2° are analysed carefully to detect stripped protons and persistent deuterons. The average multiplicity of stripped protons and survival probability of deuterons is estimated as follows:

$$\text{Stripping rate} = \frac{\text{No. of persisting protons}}{\text{No. of interacting deuterons}} = 0{\cdot}21 \pm 0{\cdot}05\,,$$

$$\text{Survival probability} = \frac{\text{No. of persisting deuterons}}{\text{No. of interacting deuterons}} = 0{\cdot}16 \pm 0{\cdot}04\,.$$

The statistics on which our results are based is quite poor but it is evident that at relativistic energies the stripping rate falls and the survival probability tends to increase as predicted earlier [16]. Considering the deuteron-nucleus interactions as a whole equivalent to simultaneous independent interactions of the proton and neutron, the total stripping probability will turn out to be double the stripping rate for protons alone. Thus our value of $0{\cdot}42 \pm 0{\cdot}10$ for stripping probability of 10 GeV/c deuteron beam is in good agreement with the values of 0·42 and 0·50 reported by Galstyan et al. [1] and Badyal et al. [3], respectively.

MULTIPLICITY

In our analysis a systematic record of all secondary particles produced in $d-n$ interactions is made by classifying all the prongs into three categories viz. black, gray and shower according to standard criteria [1, 3].

The multiplicity distributions for shower, gray and heavy (black and gray) prongs are shown separately in figs. 1 (a, b, c). The shower prong distribution (fig. 1a) shows slightly a bimodal character with two peaks. The first peak at $n_s = 1$ can be explained due to stripped protons and $d-n$ interactions of extreme peripheral type.

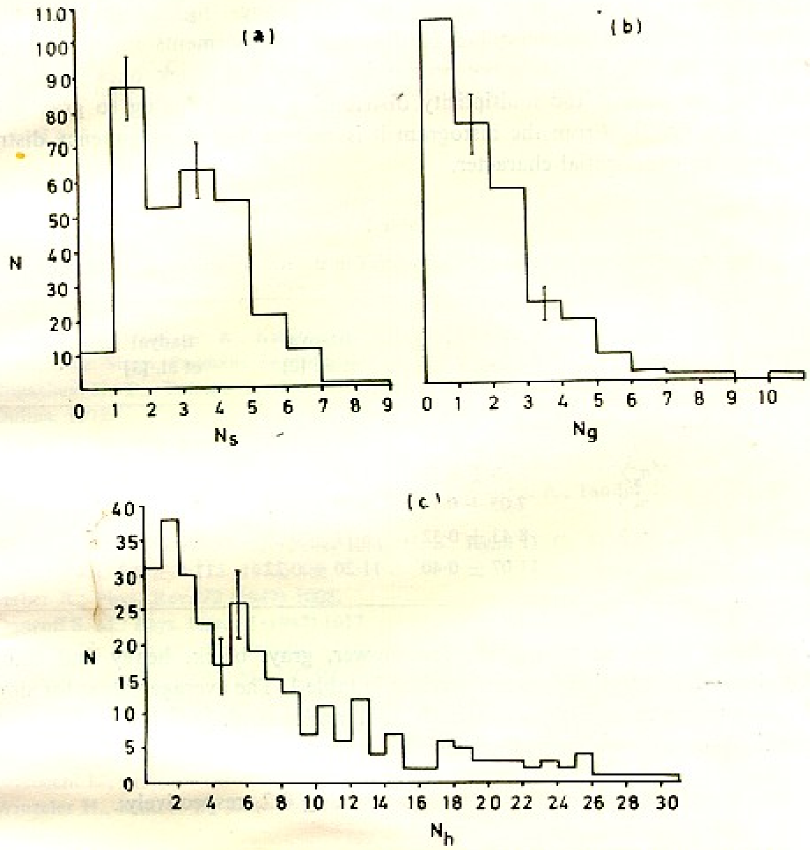

Fig. 1. Multiplicity distribution: (a) shower prongs, (b) gray prongs, (c) heavy prongs.

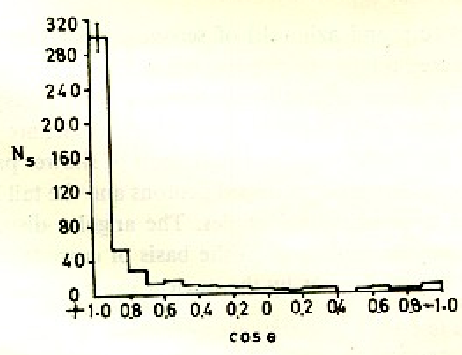

Fig. 2. Angular distribution of shower prongs.

The multiplicity distribution for heavily ionizing prongs (fig. 1c) shows a distinct multimodal structure by a number of dips and enhancements in the histogram.

Although the division of heavy prongs into gray and black ones is not very precise yet we present the multiplicity distribution corresponding to gray prongs separately in fig. 1b. From the histogram it is evident that this frequency distribution shows an exponential character.

Table 1

Mean multiplicities of charged secondaries in d—n interactions at 10 GeV/c.

Mean multiplicity	Present work	Basova et al. [2]	Badyal et al. [3]
$\langle n_s \rangle$	$2{\cdot}64 \pm 0{\cdot}15$	$3{\cdot}08 \pm 0{\cdot}05$	$3{\cdot}1 \pm 0{\cdot}1$
$\langle n_g \rangle$	$1{\cdot}38 \pm 0{\cdot}11$	$2{\cdot}34 \pm 0{\cdot}07$	$2{\cdot}0 \pm 0{\cdot}1$
$\langle n_b \rangle$	$7{\cdot}05 \pm 0{\cdot}14$	$5{\cdot}78 \pm 0{\cdot}15$	$6{\cdot}5 \pm 0{\cdot}2$
$\langle n_h \rangle$	$8{\cdot}43 \pm 0{\cdot}32$	$8{\cdot}12 \pm 0{\cdot}20$	$8{\cdot}5 \pm 0{\cdot}3$
$\langle n_{ch} \rangle$	$11{\cdot}07 \pm 0{\cdot}40$	$11{\cdot}20 \pm 0{\cdot}22$	$11{\cdot}6 \pm 0{\cdot}3$

The mean values of multiplicity for shower, gray, black, heavy and charged prongs in d—n interactions are summarized in table 1. The average values for shower and heavy prong multiplicities obtained by Winzeler et al. [17] for proton-nucleus interactions at 7 GeV/c in nuclear emulsions are:

$$\langle n_s \rangle = 2{\cdot}8 \pm 0{\cdot}1 \text{ and } \langle n_h \rangle = 8{\cdot}8 \pm 0{\cdot}2, \text{ respectively.}$$

ANGULAR DISTRIBUTIONS

The emission angles (dip and azimuth) of secondary particles produced in d—n interactions were measured relative to primary beam direction in the emulsion plates. Most of the shower prongs are emitted in the forward cone. Heavy prongs produced in the deuteron interactions with H-group of emulsion nuclei are emitted in all random directions. Fig. 2 shows the angular distribution of shower particles with a well pronounced forward peak formed by stripped protons and the tail by a small fraction of particles emitted at large azimuthal angles. The angular distribution of shower prongs in white stars may be explained on the basis of cascade mechanism and the random distribution of heavy prongs by the nuclear evaporation process.

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