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$\bar{p}$-^{3}He REACTION CROSS SECTION AT 200 MeV/c

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ABSTRACT

Inelastic $\bar{p}$-^{3}He events at 192.8 MeV/c are detected with a self-shunted streamer chamber. The reaction cross section is 392.4±23.8 mb. This result is discussed within the framework of the Glauber theory.

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1. Experimental apparatus

In this paper we report the measurement of the reaction cross section (non elastic processes) of the interaction of 192.8 MeV/c $\bar{p}$ with ^3He nuclei. The events were detected by means of a self-shunted streamer chamber in a magnetic field exposed to a $\bar{p}$ beam of LEAR at CERN and recorded on pairs of photographic films. The experimental apparatus is described in detail in Ref.1 with the exception of the recovery and purifier system necessary to handle the very expensive ^3He gas, which will be illustrated in the following.

The system used to fill the streamer chamber with ^3He and to maintain the purity of the target with the proper localizing admixtures, consists of a pump which circulates the gas through the chamber and the purifier itself, a filling/evacuation pump connected to the ^3He cilinder outlet, a Freon-114 inlet, a Freon-22 refrigerator, a liquid Nitrogen trap, two activated carbon filters cooled with liquid Nitrogen, two molecular sieves for oxygen and water vapor and a number of valves to tune the fluxes and to insert/exclude traps in the circuits. Two sensors connected to the purifier compare the relative pressure of the streamer chamber with minimum and maximum references at the mbar level (see Fig. 1).

Assuming that the streamer chamber is filled with air, the first step of the ^3He-filling procedure is to push the air out by fluxing through the chamber, connected in open circuit, a volume of Freon-114 equal to 10 times the chamber volume. Freon-114 is heavier than air and has sufficiently high boiling point. The chamber is then connected with the purifier system in a closed loop and a slow circulation is started. The Freon-22 refrigerator is put into operation in order to liquefy (at -90° C) the Freon-114, which is automatically replaced by ^3He accordingly to the information of the pressure sensors.

When no more Freon-114 is collected by this refrigerator, the liquid Nitrogen trap, downstream, is activated and the fluxing rate is increased in order to sublime a further part of Freon-114.

After a while, an activated carbon filter is also inserted downstream. Finally, when no more ^3He is required by the system, a molecular sieve is put into operation to trap oxygen and water vapour. Now pure ^3He is circulating through the chamber and the purifier and little quantities of iso-C_4H_{10} can be added to the target gas in order to improve track localization. This admixture is gradually absorbed by the several traps of the purifier.

From the recorded fluxes of ^3He and iso-C_4H_{10} we can evaluate percentages of iso-C_4H_{10} between about 0.14% and about 0.44% depending on the different operating conditions at the beginning and at the end of data-taking runs.

2. *Measurement of the cross section.*

The $\bar{p}$-^{3}He interaction at 192.8 MeV/c includes elastic and non elastic processes. The latter ones include $\bar{p}$-proton charge exchange, break-up and annihilation. The charge exchange reaction are:

$$
\begin{array}{lll}
\bar{p}\,^3\mathrm{He} \to & \bar{n}\,t & (1) \\
 & \bar{n}\,d\,n & (2) \\
 & \bar{n}\,2p\,n & (3)
\end{array}
$$

with a threshold of 5.06 MeV; n means neutron, d deuteron and t triton.
The break-up reactions are:

$$
\begin{array}{lll}
\bar{p}\,^3\mathrm{He} \to & \bar{p}\,d\,n & (4) \\
 & \bar{p}\,2p\,n & (5)
\end{array}
$$

with a threshold of 7.27 MeV.

The annihilation process on ^{3}He consists of a $\bar{p}$-nucleon annihilation which may be preceded by the reactions (1-5) and/or followed by π-nucleon scattering. The $\bar{p}p$ annihilation produces, on the average, 1.5 π^+, 1.5 π^- and 2 π°; the $\bar{p}n$ annihilation produces, on the average, 1 π^+, $2\pi^-$ and 2 π°. The reactions are of the following type:

$$
\begin{array}{lll}
\bar{p}\,^3\mathrm{He} \to & 2n + (k+1)\,\pi^+ + k\,\pi^- + h\,\pi^0 & (6) \\
 & p + n + k\,\pi^+ + k\,\pi^- + h\,\pi^0 & (7) \\
 & d + k\,\pi^+ + k\,\pi^- + h\,\pi^0 & (8) \\
 & 2\,p + k\,\pi^+ + (k+1)\,\pi^- + h\,\pi^0 & (9)
\end{array}
$$

where h, k = 0,1,2,... and the strange particles are neglected (they are present in a few percent of the events). Reaction (8) is due to $\bar{p}p$ annihilation only. Reaction (9) may be due to $\bar{p}n$ annihilation or to reaction (8) followed by $\pi^\circ n \to \pi^- p$ charge exchange and so on (a similar situation is described for ^{4}He in Ref.3). The maximum number of charged prongs observed is 7 (see table I).

We note that all the reactions (1-9) produce an odd number of charged prongs and the number of positive prongs exceeds that of the negative ones by one. These features allow us to avoid confusion with the elastic events. In fact, these have two detectable charged prongs

(the scattered $\bar{p}$ and the recoil nucleus) or have one negative prong.

The procedure for reconstructing the events is described in Ref.2. All the events with a number of charged prongs ≥ 5 are annihilations. Events with 1 or 3 charged prongs may be either annihilations or break-up and charge exchange reactions. The latter do not produce pions. We recognize the different types of events by means of kinematical fits and by analyzing the ionization of the tracks following the criteria adopted in previous works on ^{4}He [2,5]. Of 272 non elastic events; 92% are annihilations, 2% break- up reactions and 6% are not identified. As expected, the majority of the events are annihilations. These events were detected in a central region of the sensitive volume of the streamer chamber (≈50 cm in length), where the detection efficiency is 100%.

The procedure for the evaluation of the cross section is the same as that followed for the $\bar{p}$-^{4}He [3] and $\bar{p}$-Ne [4] interactions. The reaction cross section is evaluated by the formula:

$$\sigma_R = \frac{A}{\rho\, l\, N_{AV}} \frac{N_{ev}}{N_i}$$

where N_{AV} is the Avogadro number, A is the atomic weight, N_{ev} is the number of non elastic events, N_i the number of incoming $\bar{p}$ ($N_i = 586014$), ρ the density (g/cm^3) of the gas target at the proper values of pressure (P=969.8 ±0.1% mbar) and temperature (T=291.4±0.3% °K) and l the mean length of a number of undeviated $\bar{p}$ tracks within the central region of the sensitive volume mentioned above (l=48.7±0.09 cm). We obtained the value σ_R=392.4±23.8, where the error is the statistical one.

The are also two systematic errors: one due to the uncertainty of the target transparency (±2.3 mb) and the other due to the admixture of ≈ $3^o/_{oo}$ of iso-C_4H_{10} to the ^{3}He gas. Annihilation on H only produces events with an even number of charged prongs and annihilation on C produces both even charged prong and odd charged prong events. The latter may be confused with events on ^{3}He if the number of the positive prongs exceeds that of the negative prongs by one. Knowing the annihilation cross section on H and C [4,6,7,8,9], it is possible to evaluate the yields of such events. The evaluated number of even prong events agrees with the number of even prong events detected in the streamer chamber. All considered, we estimate a possible contribution of spurious events with an odd number of charged prongs to be less than about 1.1% of the detected events, which corresponds to an uncertainty on the cross section of ≈ 4.3 mb.

Also considering the number of the unidentified events, the cross section for the reactions (1-4) is 31.4 mb at most, a value much smaller than $\sigma_R = 392.4$, in agreement with the result on ^{4}He [5].

In Fig.1 the value of the reaction cross section for ^{3}He is compared with the data concerning other light nuclei.

3. *Comparison between the ^{3}He and ^{4}He reaction cross sections*

In this section we compare the value of the reaction cross section $\bar{p}$-^{4}He at 192.8 MeV/c $\sigma_R(^4\mathrm{He}) = 405.6 \pm 16.4$ mb measured by us in a previous work [3], to the present result $\sigma_R(^3\mathrm{He}) = 392.4 \pm 23.8$ mb. These two results are surprisingly close.

The analysis is performed in the framework of the Glauber model, which gives reliable results when the eikonal approximation holds, as in the case of the high energy (> 1 GeV) p-nucleus scattering (see for instance ref.12). We omit here the discussion on the applicability of this model to the low energy $\bar{p}$-nucleus scattering, because this argument is treated in detail in some recent works [13,14,15]. We recall only that the model allows the $\bar{p}$-neutron scattering amplitude at 600 MeV/c to be determined univocally (within the experimental uncertainties) by fitting $\bar{p}$ elastic scattering data on different nuclei [15]; moreover, it gives values of the $\bar{p}$-nucleus total reaction cross section in very good agreement with the experimental data down to 300 MeV/c [4,16,17]. Concerning the case discussed here (200 MeV/c), we emphasize that, at this very low momentum, the validity of the theory is somewhat questionable, although some calculations satisfactorily reproduce the experimental values of total cross sections [17]. Moreover, the parameters of the $\bar{p}$-p and $\bar{p}$-n scattering amplitudes (in particular, the slope parameter), which are input quantities in the Glauber model, are not well known below 300 MeV/c[6,18].

For these reasons, we think that here one must be careful in deriving conclusions from the comparison between calculated and experimental total cross sections. Nevertheless, we think that it is correct to use the Glauber theory to ascertain whether the measured equality between the ^{3}He and ^{4}He reaction cross sections is due only to a "geometrical effect", that is to the size of these nuclei combined with the shadow effect among the nucleons, or to peculiar aspects of the interaction of $\bar{p}$ with few nucleon systems.

We calculate the reaction cross section by the formula:

$$\sigma_R = \frac{4\pi}{k} \operatorname{Im} F_N(0) - 2\pi \int | F_N(\theta) |^2 \sin\theta \, d\theta \qquad (10)$$

where k is the laboratory incident momentum and F_N is the Glauber nuclear scattering amplitude calculated with the same procedure described in detail in Ref.[15], having as input quantities the elementary scattering amplitudes of the $\bar{p}$ with a free nucleon:

$$f_j(q) = \frac{k}{4\pi} \sigma_j (i+\rho_j) \exp(- \frac{1}{2} \beta_j^2 q^2) \qquad (j = \bar{p}\,p\,,\bar{p}\,n\,)$$

The six input parameters σ_j, ρ_j and $\beta^2{}_j$ are determined as follows.

The values of $\sigma_{\bar{p}p}$=334.0 mb and $\rho_{\bar{p}p}$=0.1 are taken from $\bar{p}p$ elastic scattering data [18], that of $\sigma_{\bar{p}n}$=274.0 mb from $\bar{n}p$ data [19] (charge invariance implies $\sigma_{\bar{p}n} = \sigma_{\bar{n}p}$). The values of $\beta^2{}_j$ measured around 200 MeV/c are affected by a large error. The interpolation of data from Refs. [6] and [18] gives $\beta^2{}_{\bar{p}p}$=73±20 $(\mathrm{GeV/c})^{-2}$, whereas the extrapolation to lower energy, with an empirical formula, of higher energy data gives $\beta^2{}_{\bar{p}p}$=48 $(\mathrm{GeV/c})^{-2}$ [17]. The values of $\beta^2{}_{\bar{p}n}$ and $\rho_{\bar{p}n}$ at 200 MeV/c are totally unknown. Since the total reaction cross section is nearly independent of ρ [17], we put $\rho_{\bar{p}p}=\rho_{\bar{p}n}$; moreover, since at 300 MeV/c the condition $\sigma_{\bar{p}p}/ \sigma_{\bar{p}n} = \beta^2{}_{\bar{p}p}/\beta^2{}_{\bar{p}n}$ seems to hold [15] and is physically justified when $\rho_{\bar{p}p}$~$\rho_{\bar{p}n}$<<1 and the $\bar{p}$-nucleon amplitude is forward peaked [14], we put also

$$\beta^2{}_{\bar{p}n}= \beta^2{}_{\bar{p}p}(\sigma_{\bar{p}n}/ \sigma_{\bar{p}p}) \qquad (11)\,.$$

The radii of the distributions of the nucleon centers, which define in the Glauber model the size of the nucleus, have been fixed as R(^{4}He)=1.37 fm and R(^{3}He)=1.56 fm according to Refs.[15] and [20], respectively.

In this way, all the input parameters are determined, except for $\beta^2_{\bar{p}p}$ and $\beta^2_{\bar{p}n}$, so we make the calculations assuming for $\beta^2_{\bar{p}p}$ both the values mentioned above (48 and 73 (GeV/c)$^{-2}$) and calculate $\beta^2_{\bar{p}n}$ by eq.(11) and σ_R by eq.(10). The results are reported in Table II.

We see that a good agreement with our data is achieved for $\beta^2_{\bar{p}p}$= 48 (GeV/c)$^{-2}$ and $\beta^2_{\bar{p}n}$=39 (GeV/c)$^{-2}$. However, in the light of the above discussion on the reliability of the Glauber theory, this result cannot be considered as a new determination of these two parameters. Nevertheless, Table II shows that the calculated reaction cross sections on ^{3}He and ^{4}He are equal within 10% for both the sets of input parameters utilized, in agreement with our measurements.

This indicates that the equality $\sigma_R(^3\text{He}) \approx \sigma_R(^4\text{He})$ is explainable by assuming that in ^{3}He the number of nucleons lower than in ^{4}He is compensated by a smaller shadow effect due to the larger ^{3}He size.

We recall that at 300 MeV/c a similar situation occurs for ^{2}H and ^{4}He: in a previous measurement [3] we obtained $\sigma_R(^4\text{He})$= 293.7±9.1 mb, a value close to that measured in a deuterium bubble chamber at the same momentum [11] $\sigma_R(^2\text{H}) \approx 311$ mb (see fig. 1). However, here the Glauber theory reproduces our reaction cross section value for ^{4}He well, but predicts a sensibly smaller value for ^{2}H, if the same $\bar{p}$-nucleon scattering amplitudes are used[17]. Hence, it seems that the equality $\sigma_R(^4\text{He}) \approx \sigma_R(^2\text{H})$ cannot be explained in terms of a geometrical effect.

Obviously, to clarify the situation, new measurements on ^{3}He and ^{2}H at low energy are needed.

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TABLE CAPTIONS

Table I: Charged prong multiplicity distribution in the $\bar{p}$-^{3}He annihilation.

Table II :Reaction cross sections (mb) on ^{3}He and ^{4}He calculated with the Glauber model in correspondence with two different values of the $\beta^2{}_j$ parameters (GeV/c)$^{-2}$. For a comparison, also the experimental values of the reaction cross section on ^{3}He (this work) and on ^{4}He Ref.[3] are reported. The values of the other input parameters of the Glauber model are reported in the text.

TAB. I

M	%
1	8.8±2.6
3	43.0±4.6
5	43.0±4.6
7	5.3±2.1

TAB. II

$\beta^2_{\bar{p}p}$	73.	48.
$\beta^2_{\bar{p}n}$	60.	39.
$\sigma_R(^3He)$	466.	393.
$\sigma_R(^4He)$	502.	414.
$\sigma^{exp}_R(^3He)$	392.4±23.8	
$\sigma^{exp}_R(^4He)$	405.6±16.4	

FIGURE CAPTIONS

Fig. 1: Sketch of the recovery and purifier system for the ^{3}He gas.

Fig. 2: Reaction cross sections as a function of the $\bar{p}$ momentum for different light nuclei. (○) : $\bar{p}$-^{2}H, R. Bizzarri et al. Ref.[10]; (•): $\bar{p}$-^{2}H, T.E. Kalogeropulos et al., Ref.[11]; (×): $\bar{p}$-^{1}H, V. Chaloupka et al., Ref.[7]; (+): $\bar{p}$-^{1}H, W. Brückner et al., Ref.[6]; (▲): $\bar{p}$-^{4}He, F. Balestra et al.,Refs. [3] and [5]; (□) : $\bar{p}$-^{3}He, this work; (■): $\bar{p}$-^{4}He --> ^{3}He + anything, F. Balestra et al.,Ref. [3] .

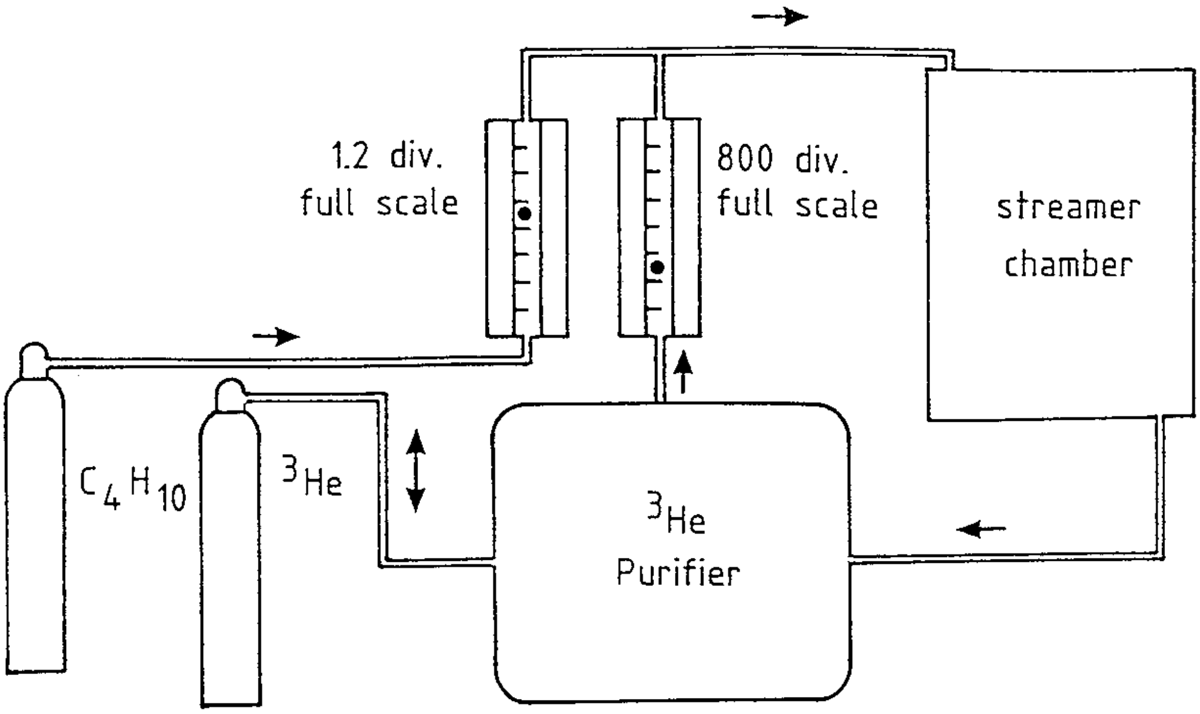
1.2 div.
full scale
800 div.
full scale
streamer
chamber
C_4H_{10}
^{3}He
^{3}He
Purifier

Fig. 1

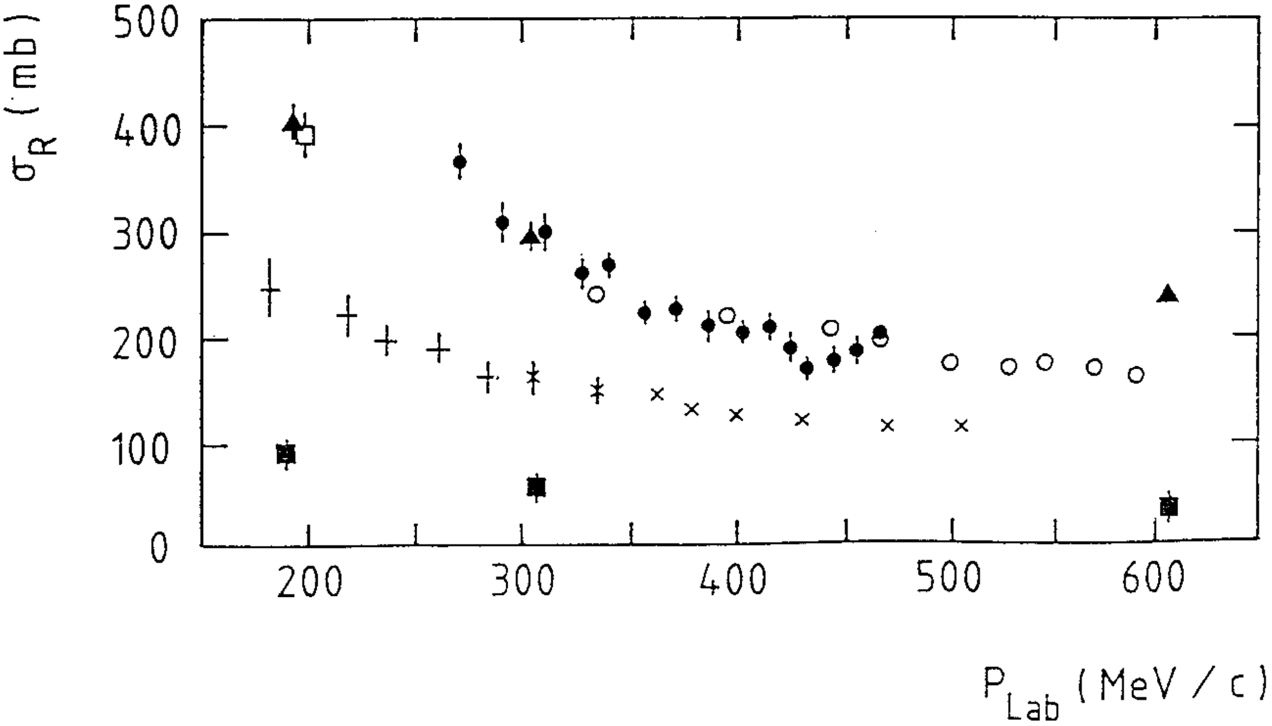
σ_R (mb)
500
400
300
200
100
0
200
300
400
500
600
P_{Lab} (MeV / c)

Fig. 2