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L. Bulgarelli, S. Focardi, E. Zavattini, M.P. Zerbetto: ON THE RAMSAUER EFFECT IN THE $d\mu + p \rightarrow d\mu + p$ CROSS SECTION AT 0.2 eV.

The gap lengths between stopped muons and rejuvenated muons in a bubble chamber filled with deuterated hydrogen were measured at two different deuterium concentrations. The results thereby obtained were compared with those expected from the calculated $d\mu + p$ and $d\mu + d$ elastic scattering cross-sections. The best agreement was found only by assuming the existence of the Ramsauer effect in $d\mu + p$ elastic scattering at 0.2 eV.

Muon rejuvenation was observed, for the first time, in hydrogen with natural concentration of deuterium, by Alvarez et al.[(1)]. It has been observed that the rejuvenated muons were not infrequently displaced from the end of the incident stopped muon by a gap length up to 1 mm. It was found that the maximum length of the gaps decreased by increasing deuterium concentration. No gap was observed with a deuterium concentration of 4.3%[(2)]. Process occurring after the stopping of a negative muon in a bubble chamber filled with deuterated hydrogen has been described in detail by several authors[(3)]. The existence of a rejuvenated muon involves a transition of the μ meson (according to $p\mu + d \rightarrow d\mu + p$ reaction) from hydrogen to deuterium. In this process the $d\mu$ system gains 45 eV. This very large initial energy (compared with thermal energy $\approx$ 0.002 eV) causes the observed gaps. The energy losses process depends on cross-sections $d\mu + p \rightarrow d\mu + p$ and $d\mu + d \rightarrow d\mu + d$. Such cross-sections have been calculated by Cohen et al.[(4)]. Fig. 1a shows the energy dependence of $\sigma_{(d\mu+d \rightarrow d\mu+d)}$: As shown by Cohen et al. the $\sigma_{(d\mu+p \rightarrow d\mu + p)}$ depends on large distance interactions (greater than 20 muon Bohr orbits). In particular, if large distance corrections are taken into account, the phase shift changes its sign around 0.2 eV. This leads therefore to a Ramsauer-Townsend effect in this energy region. The behaviour of $\sigma_{(d\mu + p \rightarrow d\mu + p)}$ is given in Fig. 1b both with and without large distance corrections. A comparison between large value of

$$\sigma_{(d\mu + d \rightarrow d\mu + d)}$$

with respect to

$$\sigma_{(d\mu + p \rightarrow d\mu + p)}$$

explains why gap lengths decrease by increasing deuterium concentration.

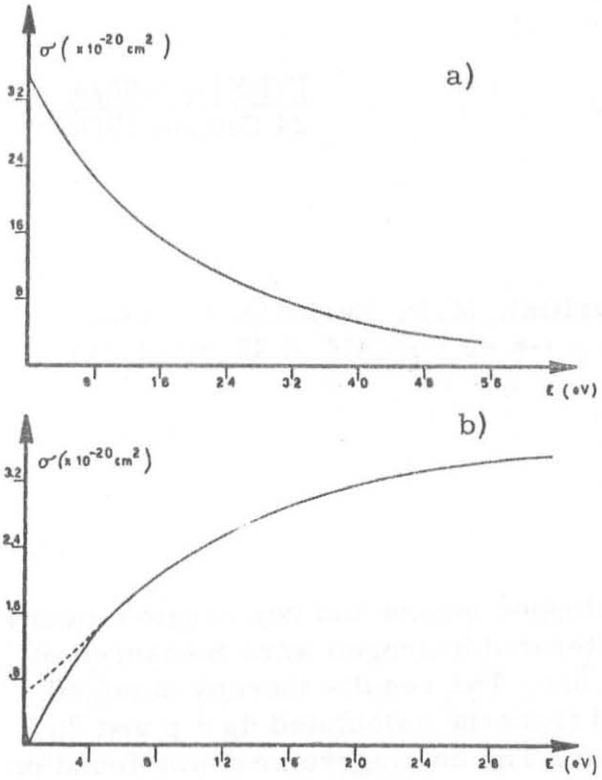

FIG. 1 - Cross section versus center of mass energy for (a) $d\mu + d \longrightarrow d\mu + d$ and (b) $d\mu + p \longrightarrow d\mu + p$.

To investigate into Ramsauer effect we have measured the "gap" lengths between stopped muons and rejuvenated muons at two deuterium concentrations $C_D = 10^{-4}$ and $C_D = 6 \times 10^{-3}$.

It was used the same film taken for an experiment of μ^- capture[5]. All measurements were performed by using digitized projectors. The only accepted events were those for which the range of rejuvanated muon was consistent with the expected value.

A "Montecarlo Method" was used to calculate the differential "gap" distributions. The program was run with a 7094 IBM computer. The slowing down process of 45 eV. $d\mu$ mesic atoms was simulated by taking into account the different possible processes, namely collisions with hydrogen and deuterium, formation of $p\mu d$ mesomolecules and decay. For $d\mu + d \rightarrow d\mu + d$ collisions, the Cohen et al.[4] cross-section was used (Fig. 1a). The $d\mu + p \rightarrow d\mu + p$ cross section was evaluated starting from phase shift calculated by Cohen et al.[4] (Fig. 1b). Other molecular parameters, namely λ_f and λ_{pd}, were taken from papers by Blaser[6] and Conforto et al.[7]. For every deuterium concentration, two different "Montecarlo" were performed by using the two different cross-sections given in fig. 1b. Only elastic processes were considered.

For each measured and calculated gap distribution, a "g" parameter was defined as follows: the number of events with gap lengths less than g is equal to the number of events with gap lengths larger than g. This parameter versus deuterium concentration for experimental and cal culated distributions is plotted in Fig. 2.

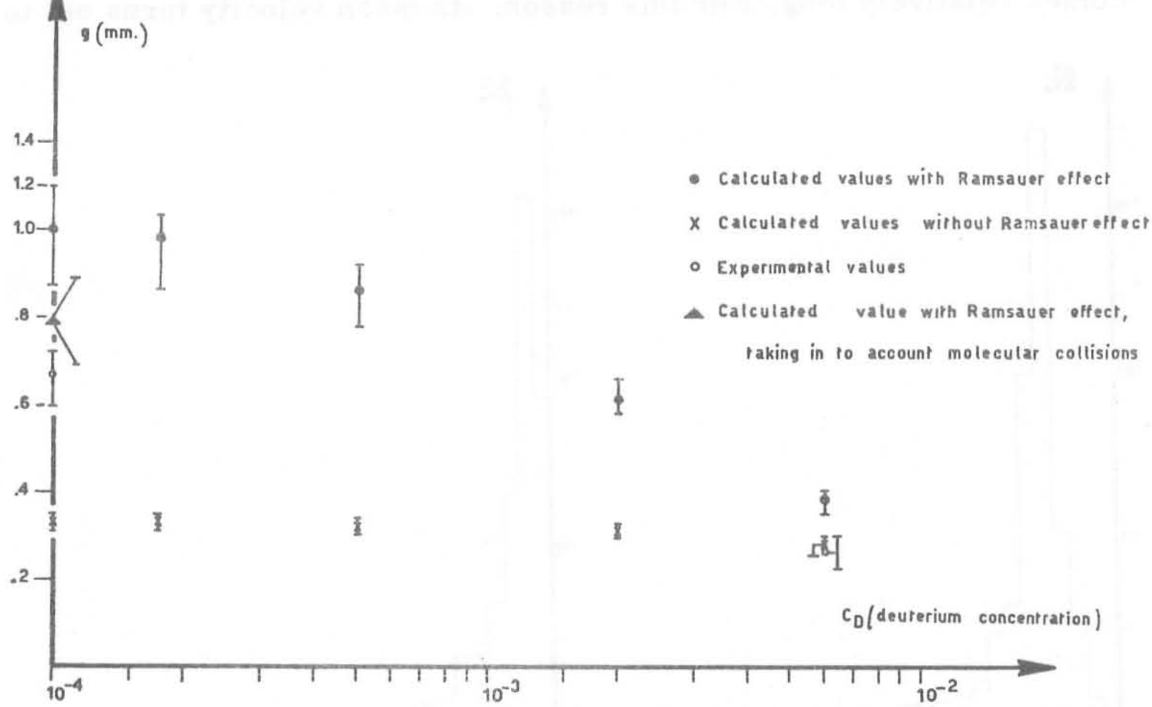

FIG. 2 - Parameter "g" versus deuterium concentration.

As shown by Fig. 2, the parameter obtained by means of expe rimental distributions decreases by increasing deuterium concentration. This behavior is not reproduced by the calculated distributions which one obtains by neglecting large distance interaction in the $d\mu + p \rightarrow d\mu + p$ cross section (dotted line in fig. 1b). As reported above, gaps disappear at large deuterium concentrations. Their presence depends on $d\mu + p \rightarrow d\mu + p$ cross section which, at low concentration, plays the largest part in the slowing down process.

For $C_D = 10^{-4}$ the chi-square test was applied to the gap experimental distribution. The values calculated by the Montecarlo method, normalized to the total number of events in the experimental distribution, were used as expected values.

A too large chi-square was found. In particular, the large gaps ($\gtrsim$ 2 mm) existing in the calculated distribution, are missing in the experimental one. A better approach was obtained by considering that, at low energy, collisions occur on molecules and not on free atoms.

The mean velocity distributions calculated with and without Ramsauer effect, are shown respectively in fig. 3a and 3b. In every Montecarlo trial, the mean velocity was defined as the ratio between the total length travelled by $d\mu$ and the corresponding time. The peak of Fig. 3a is formed by events whose abscissa has a value near the v^{*} velocity for which the $d\mu + p \rightarrow d\mu + p$ cross section is minimum. In fact when in the thermalization process a $d\mu$ velocity is not far from v^{*}, its mean free path becomes relatively long. For this reason, its mean velocity turns out to

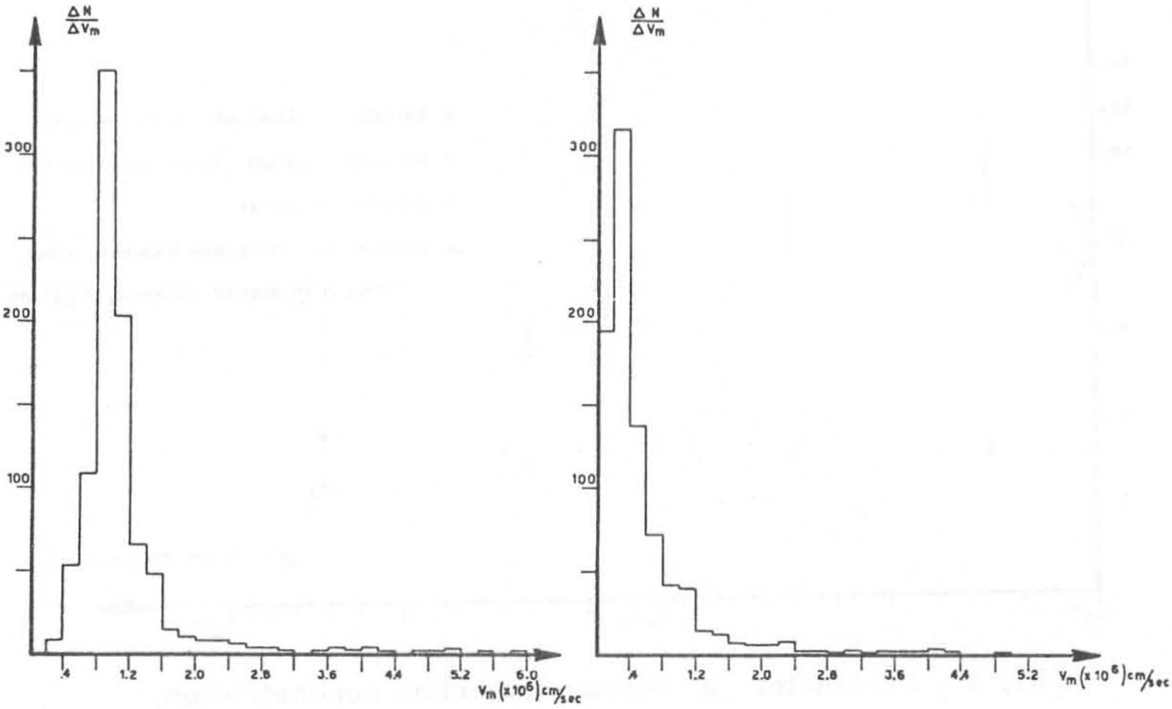

FIG. 3 - Mean velocity distribution calculated (a) with Ramsauer effect and (b) without Ramsauer effect, for $C_d = 10^{-4}$.

be not very different from v^{*}.

The mean velocity distribution calculated by means of the Ramsauer effect, was examined for gap lengths greater than 2 mm. All events were found lying around v^{*}. This correlation suggests that a suppression of large gaps can be obtained by a mechanism which reduces the number of events near v^{*}. For instance, the excitation of vibrational and rotational levels causes inelastic energy losses larger than elastic ones in the thermalization process. It is thus possible to explaine qualitatively the too large chisquare values, by reminding that only elastic collisions were considered in our calculations.

Dzhelepov et al.[8] measured the $d\mu$ gap distribution using a diffusion chamber.

They also analyzed the $d\mu$ gap distribution obtained by Schiff[9] in a preceeding experi ment with bubble chamber, with about 60 events.

The conclusion of these authors, based essentially on the analysis of Schiff data, is in favour of the Ramsauer effect.

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