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G. Matone : DIFFUSION OF THE (μ^-p) SYSTEM IN A GASEOUS
HYDROGEN TARGET

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Diffusion of the (μ^-p) System in a Gaseous Hydrogen Target.

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Introduction.

When a μ^- -meson is stopped in a H_2 gaseous target, it forms a bound system (μ^-p) , that in the ground state can be in a singlet ($s=0$) or triplet state ($s=1$) of total angular momentum.

The energy difference between these two states is 0.183 eV and, owing to the multiple scattering on the hydrogen molecules, transitions between them can occur to modify the initial mixture of $\frac{1}{4}$ for the singlet and $\frac{3}{4}$ for the triplet state.

We study the slowing down of the (μ^-p) system taking into account the elastic and inelastic scattering and neglecting either the transfer processes of the μ^- -meson to the impurity or the molecular ion $(p\mu p)^+$ formation.

1. - Scattering lengths.

The (μ^-p) scattering on free protons can be described analytically as a proton-proton diffusion in an attractivelike Morse potential for the symmetric state and in an exponential repulsive potential for the antisymmetric state.

In this way GERSHTEIN and ZEL'DOVICH⁽¹⁾ obtain the following values (in mesic units):

$$a_g = -17.3, \quad a_u = 5.25,$$

for the scattering length in the symmetric and antisymmetric state, respectively.

Besides this approach, COHEN, JUDD and RIDDEL⁽²⁾ perform a perturbation calculation and find the same value for a_u but a considerably bigger value for $a_g = -11.0$.

Experimentally, assuming correct the value $a_u = 5$, the two following values of a_g are obtained⁽³⁾:

$$a_{g1} = -18.8 \pm 0.2, \quad a_{g2} = -11.2 \pm 0.2;$$

(¹) Y. B. ZEL'DOVICH and S. S. GERSHTEIN: *Sov. Phys. JETP*, **3**, 451 (1959); *Sov. Phys. Usp.*, **3**, 593 (1961).

(²) S. COHEN, D. L. JUDD and R. J. RIDDEL jr.: *Phys. Rev.*, **119**, 384 (1960).

(³) A. ALBERIGI QUARANTA, A. BERTIN, P. DAL PIAZ, G. MATONE, F. PALMONARI, A. PLACCI, G. TORELLI and E. ZAVATTINI: *Nuovo Cimento*, **47 B**, 72 (1967).

they agree sufficiently well with the theoretical predictions; in particular they agree very well with the results of the calculation performed by COHEN *et al.*

The discrepancy is perhaps due to the fact that the Morse potential describes very well the interaction between the two protons at relatively small distance and provides a good determination of the energy levels of diatomic molecules, but probably it is not very suitable to describe scattering problems for which the asymptotic behaviour of the potential is determinant.

Therefore, we think it is better to assume the values $a_u = 5$ and $a_g = -11.2$ in all the following considerations.

2. - Scattering on the hydrogen molecule.

To extend these results to the scattering on the molecule, it is necessary to consider its internal structure. The energy difference between the triplet and singlet state is not enough to excite vibrational levels and, therefore, we shall consider the molecule as a simple rigid rotator.

Making use of the partition function for rotational levels, it is easy to verify that at 300 °K the probability to find a molecule in

$$J = 0, \quad J = 1, \quad J = 2, \quad J = 3$$

(J is the rotational angular momentum) is respectively 13%, 66%, 11%, 8%.

We obtain the cross-section for all the processes that can happen, extending the calculation proposed by GERSHTEIN⁽⁴⁾ for the triplet-singlet transition. The results of these calculations are reported in detail in ref. (5).

Now, taking into account that:

- 1) the (μ^- -p) system has an initial kinetic energy of about 0.55 eV⁽³⁾,
- 2) the lifetime of a μ^- -meson is 2.2 μ s,
- 3) the molecules have a Gaussian distribution of velocity,
- 4) owing to the molecular motion, the density is modified according to the effects described in ref. (6),

and neglecting:

- 1) the angular distribution of the scattering that we assume flat in the centre of mass,
- 2) the 8% of molecules in $J = 3$ and the other states of rotational angular momentum,
- 3) the nuclear-capture process,

we can obtain with a Monte Carlo method the time distribution of the triplet state; some results are shown in Fig. 1.

⁽⁴⁾ S. S. GERSHTEIN: *Sov. Phys. JETP*, **7**, 635 (1958).

⁽⁵⁾ G. MATONE: *Diffusione del sistema (μ^- -p) in idrogeno gassoso*, Frascati preprint LNF-69/5 (1969).

⁽⁶⁾ S. SCHWINGER: *Phys. Rev.*, **58**, 1004 (1940).

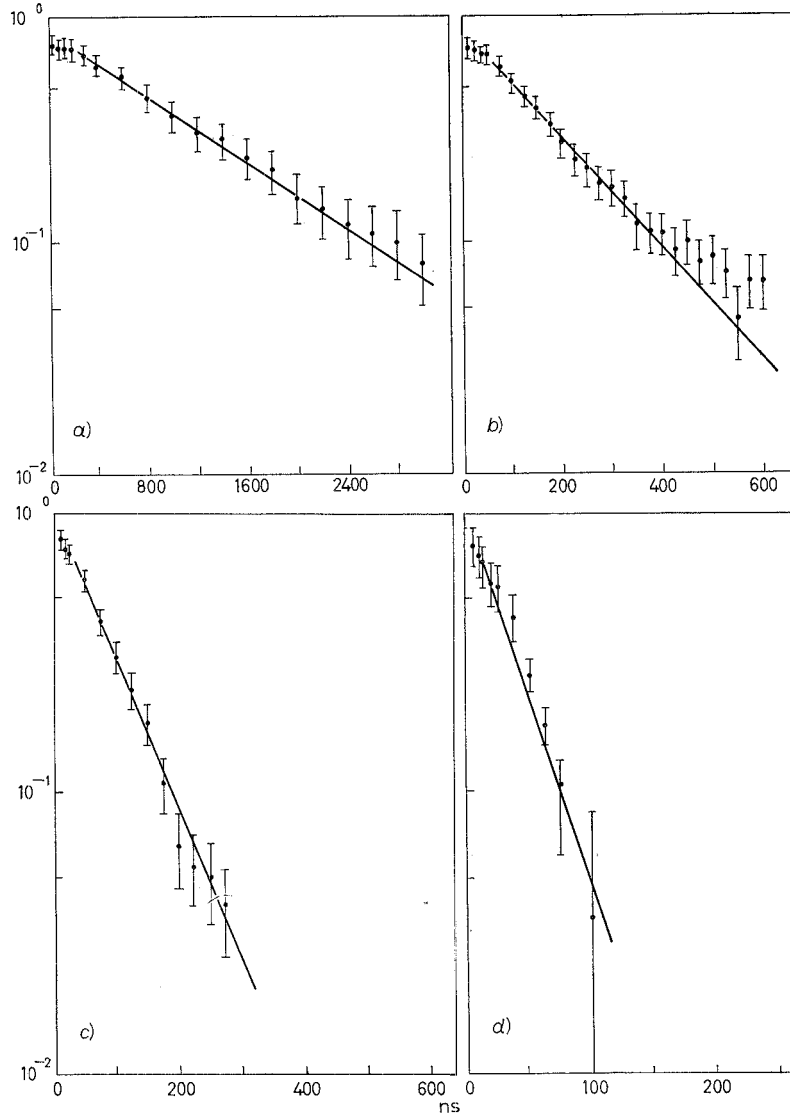


Fig. 1. - a) $\tau = (1170 \pm 100)$ ns, $\frac{1}{2}$ atm; b) $\tau = (180 \pm 19)$ ns, 5 atm; c) $\tau = (82 \pm 9)$ ns, 8 atm; d) $\tau = (31 \pm 4)$ ns, 25 atm.

3. - Conclusions.

1) In all the distributions there is an initial statistical equilibrium between triplet and singlet states.

2) After this initial time interval, the kinetic energy of the (μ^-p) system is about 0.18 eV and the time distribution shows an exponential decay where the time constant is determined by the cross-section for the triplet-singlet transition.

3) The transition rates are approximatively proportional to the gas pressure until (2÷3) atm. For lower values of the pressure, this transition rate is of the same order of the decay rate. Moreover, below 0.2 atm, the diffusion process no longer distorts the initial statistical mixture of $\frac{1}{4}$ for singlet and $\frac{3}{4}$ for triplet.

This fact can be very interesting for the possibility to measure the capture rate in the triplet state of the (μ^-p) system.

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