OBSERVATION OF MUONIC HF MOLECULE FORMATION WITH TF $\mu^{-}SR$


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Negative muon polarization has been measured in pure gaseous Ne (24 atm) and in Ne+H$_2$ mixtures (24 atm Ne + 1.8 atm H$_2$, 8 atm H$_2$ and 16 atm H$_2$). The experiment was performed at JINR (Dubna) on a $\mu$SR-spectrometer [1] with 200 G transverse magnetic field at room temperature. In pure Ne no polarization was observed ($a_0 = 0.09 \pm 0.1\%$) while in Ne+H$_2$ mixtures clear precession signals were detected at the free-muon frequency with asymmetries $a_{18} = 0.33 \pm 0.13\%$, $a_8 = 0.33 \pm 0.14\%$ and $a_{16} = 0.59 \pm 0.09\%$. The fact that polarization appears in the muonic HF molecule shows that at the moment of the molecule formation ($t \sim 10^{-10}$ s) the muon is not completely depolarized. The estimate of the reaction constant $k = (2.3 \pm 1.6) \times 10^{-11}$ cm$^3$ s$^{-1}$ agrees with the experimental values obtained by other methods. The result achieved demonstrates that $\mu^{-}SR$-method can be applied for studying fast kinetics processes in the gas phase and in particular for measuring chemical reaction rates of halogen atoms and ions.

1. Introduction

The fact that after Coulomb capture of a negative muon by an atom A$^-$ a quasi nucleus (muonic atom) A$_{Z-1}$ is formed makes the use of $\mu^{-}SR$-technique very attractive. Indeed, while the class of interactions studied by $\mu^{+}SR$, however wide it may be, is inherently restricted to interactions of $\mu^{+}$ and muonium, $\mu^{-}SR$ permits, at least in principle, to study interactions of all the elements of the Periodic Table. Unfortunately it is often difficult to make use of this fundamental advantage for the following reasons: (i) $\mu^{-}$ polarization $P_k$ after muonic atom formation is small and never exceeds 20% of its initial value; (ii) the lifetime of the bound muon is short ($\sim 80$ ns for heavy nuclei); (iii) the muonic atom A$_{Z-1}$ formed is surrounded by the host A$_Z$ atoms. Consequently only (A$_{Z-1}$, A$_Z$) interactions can be studied.

The restriction imposed by item (iii) is not important if the interaction (A$_{Z-1}$, A$_Z$) is weak and does not affect muon polarization. This can be
expected to occur in inert gases where the negative muon forms a haloid muonic atom (or ion).

The first $\mu^-$-SR-experiments with gaseous neon [2] and argon [3] (with xenon admixture) were carried out in the 1970s (see also [4]). In accordance with the prediction by Gorelkin and Smilga [5] three-frequency precession was observed, characteristic of fluorine and chlorine muonic atoms formed under such conditions. In the 1980s, in order to proceed to the study of muonic fluorine chemistry, we made an attempt to repeat the experiment [2] with a higher degree of accuracy. The $\mu^-$ asymmetry was found to be below 0.3%, which was in contradiction with the result of Ref. [2].

The question arises at what stage does muon depolarization take place: during the charge-exchange reactions of the multiply charged muonic fluorine ion (i.e. practically instantly), or later, e.g. as a result of hyperfine and spin-rotation interactions in the NeF$^+$ ion or XeF molecule products. If the former case is valid the study of muonic fluorine interactions with $\mu$SR is impossible in principle.

In order to answer this question it is essential to exclude all the "slow" depolarization processes. It is possible to do this by adding to neon a considerable amount of substance which, reacting with F$^+$ ion, will form a diamagnetic molecule. At the moment $\tau$ of such molecule formation the hyperfine interaction between the muon and unpaired electron is broken and the muon polarization becomes "frozen". In a transverse magnetic field a precession with the free muon frequency $\omega_\mu = \gamma_\mu B$ ($\gamma_\mu = 8.52 \times 10^4$ s$^{-1}$ G$^{-1}$) should be observed, with the amplitude $a_\mu$ given by the expression:

$$a_\mu = \frac{a_\tau}{\left[1 + (\omega^* - \omega_\mu)^2 \tau^2\right]^{1/2}}.$$  \hspace{1cm} (1)

where $a_\tau$ is the asymmetry at the moment $\tau$ and $\omega^* \simeq \omega_{Mu} \simeq 100 \times \omega_\mu$ is the muon precession frequency in the intermediate paramagnetic state. By varying the relative concentrations of the components, the gas pressure and the magnetic field strength it is possible to determine the molecule formation rate $\lambda = \tau^{-1}$ and to identify the different depolarization channels.

The substance we chose for this purpose was hydrogen. This choice was determined, firstly, by the fast reaction F$^+$ + H$_2$ $\rightarrow$ HF + H rate ($k_{HF} > 10^{-11}$ cm$^3$ s$^{-1}$ [7]) which makes it possible to form the HF molecule at a

\footnote{It is possible that this contradiction is due to the presence of electric field in experiment [2]. As recently shown by Krasnoperov et al. [6], electric field may play an important role in the process of muonium formation. We are planning to study the influence of electric field on $\mu^-$ depolarization in Ne$^+$Xe mixture.}