TRIUMF Experiment E614
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Slow Muon Spin Relaxation in a normal Metal

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M. Strovink spent 1.5 column in PR 34(1986)1967 for muon depolarization description. Therefore a full description is first.

1 Slow muon relaxation in aluminum.

Possible depolarizing processes during muon deceleration and thermalization are analyzed in TN-54 (Subsection 3.4).

Muon creates a quasi-free state in Al where a conduction electron concentration is $\simeq 2 \cdot 10^{23} cm^{-3}$. The polarized muon state is not stable because energy difference between parallel and anti-parallel spin states of muon in $2T$ is $\simeq 10^{-6} eV$ while thermal energy at $T = 300K$ is $kT \simeq 3 \cdot 10^{-2} eV$. Interactions with the conductive electrons, nuclear moments of Al, paramagnetic admixtures, terminal spur of muon track can create a muon spin relaxation. We will analyze possible relaxation time dependences because the interactions.

Interactions of muon spin with conductive electrons has name Korringa relaxation [1]. Conductive electrons create a big hyperfine magnetic field on muon. The field produced at a muon can be considered as fluctuating local field with a correlation time $\tau_c \simeq 10^{-13} s$ in Al [2]. Relaxation rate therefore is exponential. The Korringa relaxation rate does not depend on magnetic field. Significant relaxation rates ($\lambda > 0.001 \mu s^{-1}$) were obtained for muon in Cd, Sn, Pb, As, Sb, Bi [3]. Authors explained the measured relaxation rates by Korringa interaction because λ value increases with temperature growth in accordance with [1]. We are obtained at $H_L = 2T$ muon relaxation rate with $\lambda = 0.00155 \mu s^{-1}$. Probably it is the Korringa exponential relaxation also. Below one can see analysis of different relaxation interactions.

Nuclear moments of Al produce magnetic fields H_d of few gauss on a muon fixed in a crystal cell. According to many $\mu^+ SR$ references the dipole-dipole interactions cause muon spin relaxation rates of $\lambda_d = 0.1 - 0.3 \mu s^{-1}$ in an orthogonal magnetic field. There are non-exponential dependences of relaxation because we have a chaotic and static magnetic field. A longitudinal field H_L decreases the λ_d in $(H_L/H_d)^2$ times [4]. The dipole-dipole relaxation rate at $H_L = 2T$ will be $> 1 s^{-1}$. Its contribution is $< 10^{-5}$ during our analyzed time of $10 \mu s$. The above is correct for muon fixed in a crystal cell. Diffusion motion of muon creates variable in 3D and time magnetic fields on a muon. As result muon relaxation rate drops. The $H_L = 2T$ suppresses the rate in many times also.

A high purity aluminum of our stopping target has impurities (ppm): Cu - 0.3, Fe -

0.3, Mg - 1.2, Si - 0.8. Atom of Fe is a paramagnetic impurity only and can give a relaxation. It is an unlikely case because we have an one Fe atom on $3 \cdot 10^7$ atoms of Al. Probability for muon to reach an Fe atom is very low, but let us to suppose that a small part of muons reaches a Fe vicinity. Electron magnetic moment of the Fe atom creates on muon a magnetic field $H_e \simeq 1kG$ at distance of Al cell period of $\simeq 4\AA$. It corresponds to muon Larmor precession with frequency of $\omega_0 \simeq 10^8 s^{-1}$. The interaction causes a very fast muon relaxation of course if the muon fixed near the Fe, and Fe electron spin fixed also. But spin of Fe impurity in Al fluctuates with time $\tau_c < 10^{-10}s$ according to Ref.[5]. The fluctuations decrease a relaxation rate, and the relaxation dependence becomes exponential form at $\omega_0 \cdot \tau_c \ll 1$ [4]. We have the $\omega_0 \cdot \tau_c \simeq 10^{-2}$. Therefore this unlikely interaction with Fe impurity causes an exponential relaxation.

High-energy muon creates defects in a matter. The paramagnetic defects can produce sufficient magnetic fields on a stopped muon. Electron configuration recovers in $\sim 10^{-11}s$ in metals [6]. Therefore it can cause a fast muon relaxation only. Muon also displaces atoms in a crystal cell. The displaced atom configuration changes very slowly. Average distance between a stopped muon and a last displaced atom in graphite, for example, is $9000\AA$ [7]. A contribution of the interaction on muon relaxation is negligible of course.

Taking to account the above estimations we fitted muon relaxation by exponential dependence. Our result is $\lambda = 0.00155 \pm 0.0003 \mu s^{-1}$.

2 Short insertion.

A slow relaxation of muon spin with $\lambda = 0.00155 \pm 0.0003 \mu s^{-1}$ has been detected in our Al stopping target at $H_L = 2T$. The relaxation fitted by exponential function because only Korringa interactions with conductive electrons [1] can create a noticeable exponential relaxation at $H_L = 2T$. Influence of a magnetic impurity $(0.3ppm)$ of Fe, interactions with nuclear magnetic moments of Al, muon spin interactions with terminal spur of its track can cause a negligibly relaxation rate according to Refs.[2-7].

References

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