TRIUMF Experiment E614
Technical Note #99.4

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 an amplitude of the relaxation in $(H_L/H_d)^2$ times [4]. The amplitude at $H_L = 2T$ will be $< 10^{-6}$. 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 and converts to an exponential dependence. The $H_L = 2T$ suppresses an amplitude 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 $\simeq 4\mathring{A}$. 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. Relaxation rate $\sigma \simeq 0.02 \mu s^{-1}$ has been obtained in Al at $T > 100K$ with Fe admixture of $10ppm$ [6]. Our result is $\sigma \simeq 0.02 \mu s^{-1}$ using gaussian fitting also. The rate independence in Al from the increasing of Fe concentration in 30 times is direct evidence that the measured muon relaxation rate does not associate with the Fe impurity. The relaxation rate in [6] has been measured at an orthogonal magnetic field. The rate independence from a longitudinal magnetic field till $H_L = 2T$ is direct evidence of Korringa relaxation of muon spin in the Al.

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 [7]. 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 $9000\mathring{A}$ [8]. 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.[2-8].

References

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