Subject: Re: muon depolarization in metal targets
From: "James Bueno" <jbueno@triumf.ca>
Date: Wed, 17 Jun 2009 07:52:43 -0700 (PDT)
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Dear Dr Stoker,

Thank you for providing feedback on my internal report
on the depolarisation forms in silver and aluminium.

Below are some further responses.

Best regards,

James Bueno

> Richard
>
> Sorry for the long-delayed response; the delay is entirely my fault.
>
> The following comments are from David P. Stoker (dpstoker@uci.edu) whose
> Ph.D. thesis is the most relevant among the TRIUMF E185 documents.
>
> 1. Attachment p19, para 3: With regard to our aluminum's "convincingly
>   non-exponential" depolarisation for transverse geometry, Bueno says
>   "This suggests their muons were not highly mobile, either due to
>   impurities or defects from sample preparation. This is an interesting
>   result."
>
>   My thesis, p80 of [37]: "The muSR signal damping in Al is much larger
>   than observed in other experiments, and may be due to mu+ trapping in
>   cracks or other defects in the cold-rolled Al foils."
>
>   I'm not sure if all the target foils were cold-rolled or not.
>
>   This relates directly to the discussion in the attachment Section
>   5.3.

*** I missed this part of the thesis. We are in agreement on the
possible cause of the large aluminium depolarisation observed in the
transverse-field mode.

> 2. Attachment p19, last sentence: "There seems to be an assumption that
>   conduction electron relaxation is ummeasurably small, and that
>   nuclear moments are all that's left."

> Yes, I think that's we, or at least I, assumed:
> p2 of [37]: "In metals, unlike many other materials, the mu+ are thermalized in a quasi-free state instead of as muonium (mu+e-) where hyperfine transitions rapidly reduce the muon polarization by 50%."
> p26 of [37]: "The mu+ are thermalized in metals in a quasi-free state because the high conduction electron concentration effectively screens the mu+ from interactions with individual electrons."

*** Thank you for confirming the assumption.
*** Aside: Jess Brewer (UBC) notes that recent discoveries have shown that this is only reliably true in non-magnetic metals.

> 3. The quote from my thesis on p21 of the attachment should be referenced as "(from Section 4.3 (p29) of [37])"

*** Sorry, I will fix this in the report.

> 4. With regard to the quote from [37] "... oscillating magnetic fields ...
> are provided by the nuclear dipole moments and the lattice vibrations associated with low frequency acoustic phonons", Bueno says 'the depolarisation mechanism by "lattice vibrations" that Stoker describes in unclear'.
>
> What I intended to suggest was: nuclear dipole moments give magnetic fields, lattice vibrations make the muons see these fields oscillate, and oscillating magnetic fields of the right frequency give muon spin relaxation.

*** I still wasn't clear on the mechanism you describe, so I got some advice from Jess Brewer (UBC, musr researcher). He advised that jiggling of nuclei is at a frequency much greater than any muon Larmor frequency. Depolarisation by nuclear dipole moments can be explained with a static magnetic field at each site: the muons undergo a random walk where they hop between sites (the "strong collision model"), and at each location they experience a new, randomised field from static nuclear dipole moments. To a very good approximation, the motion of the nuclear dipoles can be neglected.

*** There is a mechanism by which hopping muons can see oscillating magnetic fields of the right frequency, but this doesn't require any motion of the nuclear dipoles: if the muon hops at exactly the Larmor frequency (~135 MHz for an external field of 1T), it "sees" a magnetic field that fluctuates at the resonant frequency to drive transitions between Zeeman states. (Since the muon moves stochastically, this mechanism is only relevant for a small fraction of hops. Usually the higher the field, the smaller the fraction, and the slower the relaxation.)

> 5. p21 - p22 says: "Equation (14) showed that a holding field suppresses the depolarisation due to nuclear dipole moments. It's not clear why the passages from these theses fail to acknowledge this."
>
> We didn't assume the nuclear dipoles to be static, which it appears Eq.(14) does. Can the same conclusion be reached when the nuclear dipoles are not static AND when the mu+ are not highly mobile (as Bueno says our Al data suggests)?

*** In a strong longitudinal field, the nuclear dipoles are static to a very good approximation. This would not be the case in zero field, since spin-1/2 nuclear dipole moments can move due to the muon's magnetic field acting on them. But with a strong external longitudinal field, the muon's magnetic field is negligible by comparison, and the nuclear dipoles can be modelled as static.

> 6. p22 says: "The theses are correct that the form is exponential for the longitudinal case, but it's not clear how this conclusion was reached."
>
> My thesis [37] assumed spin-lattice relaxation for the longitudinal case due to oscillating magnetic fields (nuclear dipoles jiggled by phonons). The data were not inconsistent with this --- Figure (4.2) caption on p32 concludes "The correlation between the putative spin-lattice relaxation times T1 and the nuclear magnetic moments suggests a real spin-lattice relaxation effect."

*** After reading Section 4.3, I see that you have a measure of T_1 in aluminium that is more precise than the published relaxation result in Jodidio et al. (Phys. Rev. D 34, 1967-1990 (1986)).
Specifically, Fig. 4.2 finds

1/T_1 = (0.48 +- 0.08) msec^{-1}.

And Jodidio et al. finds

2/T_1 = 0.43 +- 0.34

=> 1/T_1 = (0.22 +- 0.17) msec^{-1}.

I note that the text in Section 4.3 says "In principle the foregoing method provides a means of measuring \mu^+ spin-lattice relaxation time constants $T_1 \sim 10^3 \tau_\mu$". Was there a reason the more precise result from Fig. 4.2 was not used as the experiment's best measure of the relaxation in Al?

> ----- Original Message -----
> From: Richard Mischke
> To: strovink@lbl.gov
> Cc: James Bueno
> Sent: Wednesday, February 04, 2009 12:44 PM
> Subject: muon depolarization in metal targets
>
> Mark, The TWIST experiment is in the final stages of analysis for a precision measurement of the Michel parameters. One of the thesis students has produced a report on the subject of muon depolarization in our Al and Ag stopping targets (attached). Section 6 of that report reviews the contributions of your group to this topic. Would you be willing to read that section for accuracy and offer any corrections or comments? Thanks, Dick