ZERO RESIDUAL POLARIZATION OF NEGATIVE MUONS IMPLANTED IN C₆₀

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We report preliminary results on μ^- -depolarization in C₆₀. In contrast to graphite and diamond no clear μ^- -SR signal could be detected in TF-measurements in C₆₀.

Since the discovery of parity violation in the $\pi - \mu - e$ decay chain it is well known that negative muons (μ^-) implanted in graphite will preserve about 1/6 of the initial polarization when cascading down to the lowest Bohr orbital ($1\ ^2S_{1/2}$) after capture by a C-atom [1]. The loss of polarization during the cascade is well understood on the basis of spin orbit coupling [2]. Since the ^{12}C -nucleus has zero spin no further depolarization takes place in the ground state provided the electron shell is also in a zero total angular momentum state. Recent measurements by the Stuttgart group at PSI have also shown that μ^- implanted in diamond display a residual polarization of about 1/6 of its initial value [3].

Implanting polarized μ^- into the fullerene C₆₀ (containing 10% C₇₀) we made the very surprising observation that practically no residual polarization was left in the ground state. Fig. 1 shows a Fourier spectrum obtained from data taken in pyrolytic graphite and Fig. 2 a spectrum in C₆₀, both for a transverse field of 100 mT and 300 K. As can be seen there is a sizable μ^- -precession signal in graphite (fitted asymmetry 4.3(2)%, no relaxation) and essentially no signal in C₆₀ (fitted asymmetry 0.9(4)%, relaxation rate $\lambda \approx 0.5\ \mu\text{s}^{-1}$ – the spectrometer would yield an asymmetry of $\approx 24\%$ for muons conserving the full polarization). Essentially the same result was obtained at 12 K (Fig. 3).

Fig. 1. Calibration in graphite at 100 mT. Fourier power obtained from a μ SR histogram with negative muons in a pyrolytic graphite sample for a transverse field of 100 mT. The fitted signal at 13.5 MHz shows an amplitude $A = 4.3(2)\%$ and no relaxation.

Fig. 2. Fourier power for μ^- in a C₆₀ sample (with 10% C₇₀) at 100 mT and 300 K. The 13.5 MHz signal is much weaker than in graphite. A fit gives $A = 0.9(4)\%$ with a relaxation λ of approximately $0.5 \mu\text{s}^{-1}$.

This result seems to imply that the μ^- in the 1s ground state is exposed to a strong hyperfine interaction, since it is unlikely that the cascade is different from the one in graphite. Two possibilities come to mind: (i) the formed pseudo-atom with valence 3 remains in the C_{60} shell, but a double bond to one of the C-neighbours is broken and a chemical radical is formed with the unpaired electron coupling to the μ^- ; (ii) the formed pseudo-B atom is displaced to the center of the remaining cage where the neutral paramagnetic "B" with an unpaired electron in the 2p-state may be rather stable. The remaining C_{59} shell may not be stable but could rearrange to form a C_{58} shell with one C-atom expelled. Which possibility is realized is a question of energies. While the binding energy of a C-atom to C_{60} is of the order of 0.6 eV [4] the recoil energy transmitted to muonic carbon in the 2p-1s muonic transition (75 keV) is 0.25 eV. The two energies are so close that neither of the two possibilities can be easily ruled out. In both cases, μ SR signals similar to those observed upon μ^+ implantation are expected.

Fig. 3. Fourier power for μ^- in the C_{60} sample at 100 mT and 12 K. The 13.5 MHz signal, with $A = 1.0(4)\%$ and $\lambda \approx 0.5 \mu s^{-1}$, is insignificantly stronger than at 300 K (Fig. 2).

However, low transverse field (0.8 mT) measurements at room temperature did not reveal any sign of a muonium or radical-like precession pattern. This can be seen from Fig. 4, which shows another Fourier transform of the μ^- -SR signal in C_{60} , but this time at 0.8 mT. No precession frequency is indicated up to 250 MHz.

Fig. 4. Fourier power for **negative** muons in the C_{60} sample at 295 K and 0.8 mT. (Insert with the first 20 MHz expanded.) No signal indicating the existence of a chemical species with an unpaired electron coupling to the μ^- is visible.

Fig. 5. Calibration in C_{60} at 0.8 mT. Fourier power for **positive** muons in the C_{60} sample at 295 K and 0.8 mT. The insert shows the first 20 MHz expanded. The 10.9 MHz signal (muonium + muonic radicals) is fitted with $A = 4.4(2)\%$ and $\lambda = 2.0(1) \mu s^{-1}$. A μ^+ run at 10 mT indicates $A = 3.3(1)\%$ for the μ^+ signal.

In contrast Fig. 5 shows quite clearly the muonium and muonic radical low field signal obtained from μ^+ in the same sample, the combined asymmetry possessing a fitted value of 4.4(2)%. The result implies that any long lived μ^- signal must possess an asymmetry well below 1%. The more or less complete loss of μ^- asymmetry is probably a result of rapid electron spin relaxation (of the order of the hyperfine splitting frequency) or of the modulation of the hyperfine interaction due to the tumbling of the C_{60-n} "B" molecule at room temperature.

Inquiring more deeply one can ask what happens to the sixth electron of the $(C\mu^-)1s^22s^22p^2$ atom which may be lost since the pseudo "boron" atom has only an effective "nuclear" charge of +5. Since it is known that the electron affinity of the C_{60} molecule is quite strong, it is conceivable that this electron may remain attached to the C_{60-n} "B" molecule in an unpaired state and may thus interact strongly with the other unpaired electron on the "B"-site without actually forming a spin singlet configuration.

References

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