EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/SCC/77-20
12 September 1977

PROPOSAL

IMPURITY TRAPPING OF POSITIVE MUONS IN METALS

CERN[1]-Univ. Geneva[2]-Jülich[3]-Uppsala[4] Collaboration

O. Hartmann[4], E. Karlsson[4], K.W. Kehr[3], T.O. Niinikoski[1],
L.-O. Norlin[4], K. Pernestål[4], D. Richter[3], J.-C. Soulié[1]
and E. Walker[2]

G E N E V A
1977

1. THE MUON LATTICE LOCATION PROBLEM

Muon spin rotation (μSR) is a method with a great potential in certain areas of solid-state physics. It has several of the characteristics of a good spectroscopy: it is a precision method as far as frequency determinations are concerned; it can be used to determine field distributions and magnetic relaxation constants with good accuracy; it is a fast method; and it can be applied over a large temperature range.

For the interpretation of all experiments with positive muons in solids it is necessary to know at what kind of sites in the lattices the muons come to rest. This point was already stressed in our first proposal[1)] concerning muons in ferromagnets. At that time almost nothing was known about the equilibrium positions of the muons, although accurate "local field" determinations had been made in a few cases. Since then, progress has been made and there now exists a theoretical background for analysing μSR line-widths[2)] in metal single crystals so as to determine uniquely the muon interstitial sites. This has been done in copper[3)], and experiments are in progress for body-centred cubic (b.c.c.) metals like Nb and V.

2. PRELIMINARY INDICATIONS OF TRAPPING

During the course of the experiments with Nb and V it was found for the first time that the purity of the metal crystals is extremely important[4)] at least for the b.c.c. metals. The μSR line-widths as function of temperature show if (and where) the muons are frozen in at low temperature and how they start diffusing through the lattice at higher temperatures. For our Nb and V samples these curves showed a complex behaviour (Fig. 1). Our preliminary explanation is that the muons come to rest predominantly at one kind of site in the lattice and stay there if the temperature is low, but as soon as the temperature is high enough for leaving these sites the muons diffuse rapidly to the neighbourhood of an impurity atom, which then acts as a strong trap. The muons can leave these traps only at a much higher temperature. Our results for Nb with controlled amounts of N (20 ppm and 3700 ppm) show that already very small amounts of impurities in these metals seem to be able to trap almost all the muons (Fig. 2).

These results will have (at least) two important consequences:

i) If the aim of the experiment is to sample regular interstitial muon sites in the lattices, one must be extremely careful with the purity of the target material and work only at low temperatures.

ii) The μSR method offers unique possibilities to study under what conditions hydrogen-like impurities are attracted or repelled from other impurities in metals.

The first point is, of course, important for the use of μSR in the study of local spin polarization in ferromagnets. The second point can give information relevant to the problems of hydrogen interactions in metals and formation of metal hydrides -- areas with strong implications for future hydrogen-based energy systems.

3. FURTHER EXPERIMENTS ON TRAPPING

The experiments proposed here aim at a more detailed understanding of the trapping process and the properties of the trapping sites. In addition to further measurements on Nb with controlled amounts of interstitial impurities (N, C, or O), we will investigate ternary systems of the type NbH_xN_y, where x and y are of the order of 0.001-0.005. The idea behind the latter type of experiment is to see whether hydrogen at x=y fills all the traps and thus allows all the absorbed muons to diffuse freely at $T \geq 20$ K.

Other suggested experiments involve the effects on transition metal impurities (which most probably will occupy substitutional sites in these lattices).

In each case the muon experiments will provide information on the average jump rates and the activation energies for leaving sites occupied in the different temperature ranges. If the sites are well-defined it will also be possible to use the static μSR line-widths to draw conclusions about their symmetries. This is valid also for trapped muon states and may become an important source of information about the muon-impurity bound states (and maybe also for the hydrogen-impurity bound states, which are studied simultaneously by conventional methods at Jülich and Uppsala).

The Uppsala-CERN Collaboration is relatively well equipped for these kinds of studies: the sample temperature can now be controlled in the 0.5-300 K range; a major improvement of the magnet will probably allow fields of 1.0 T (needed to overcome the electric quadrupole interaction of the surrounding nuclei) with sufficient homogeneity; and the electronic arrangements are well adjusted. The samples will be prepared at Jülich, where also much general experience has been collected concerning the corresponding problem of hydrogen interactions in metals. Single crystals will be grown at the University of Geneva.

4. REQUEST FOR BEAM TIME

Twenty-five shifts in sharing mode up to the end of 1977. Extracted currents of 1 μA or more assumed.

REFERENCES

1) Uppsala-CERN Collaboration, Local magnetic fields in ferromagnetics studied by positive muon precession, PH III-75/7 (1975).

2) O. Hartmann, Quadrupole influence on the dipolar field width for a single interstitial in a metal crystal (to be published in Phys. Rev. Letters).

3) M. Camani, F.N. Gygax, W. Rüegg, A. Schenck and H. Schilling, Positive muons in copper: detection of an electric field gradient at the neighbour Cu-nuclei and determination of the site of location (to be published in Phys. Rev. Letters).

4) O. Hartmann, E. Karlsson, L.-O. Norlin, K. Pernestål, M. Borghini, T. Niinikoski and E. Walker, Diffusion of muons in V, Nb, and Ta, contribution to the 4th Internat. Conf. on Hyperfine Interactions, Madison, NJ, June 1977.

Figure captions

Fig. 1 : Line-widths of muons implanted into vanadium. Between the March and April runs the sample was annealed.

Fig. 2a : Line-widths of muons in extremely pure niobium as function of temperature. (Crosses and dots represent different runs under identical conditions.)

Fig. 2b : Line-widths of muons in vanadium doped with nitrogen and hydrogen.

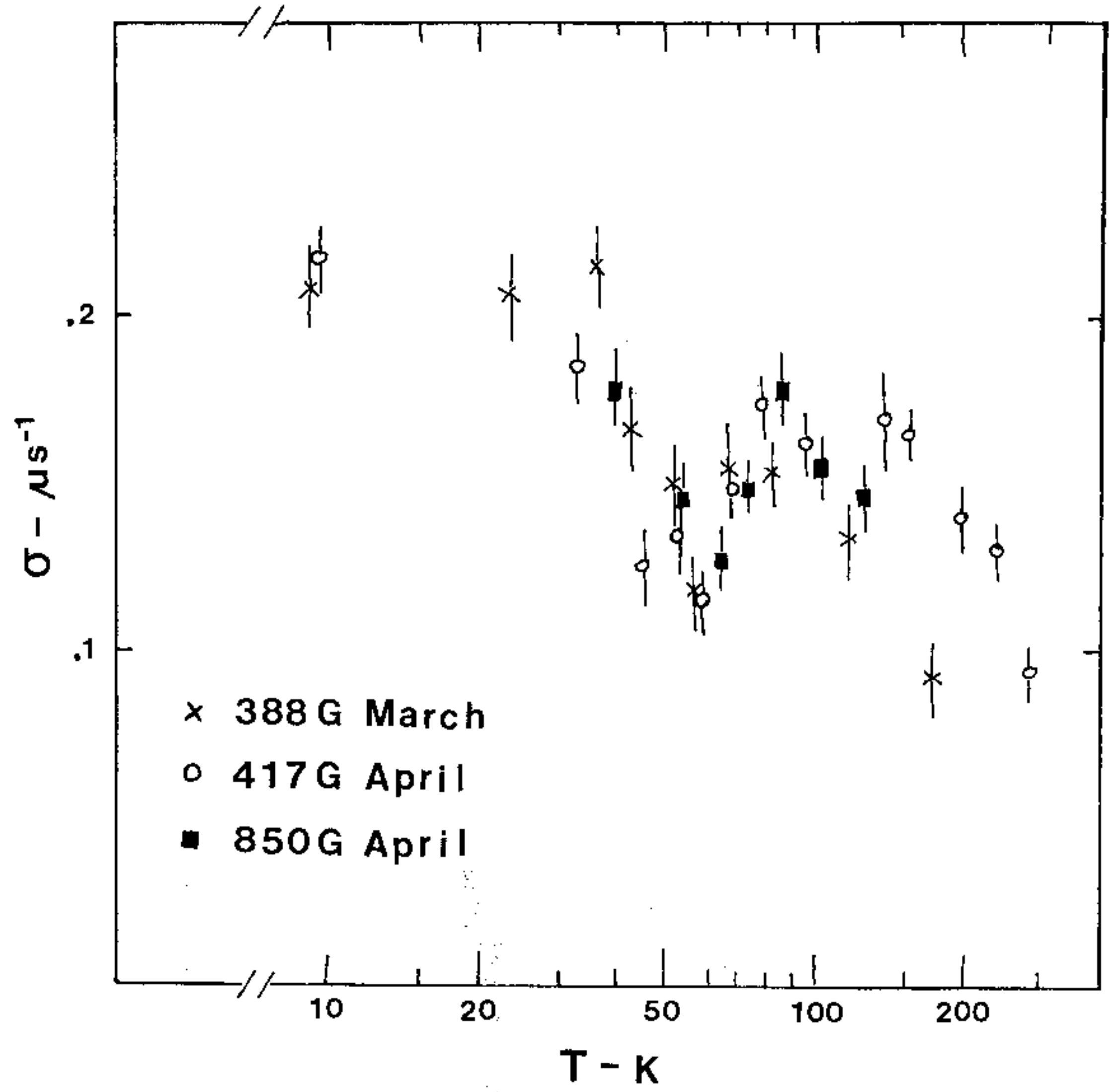

Fig. 1

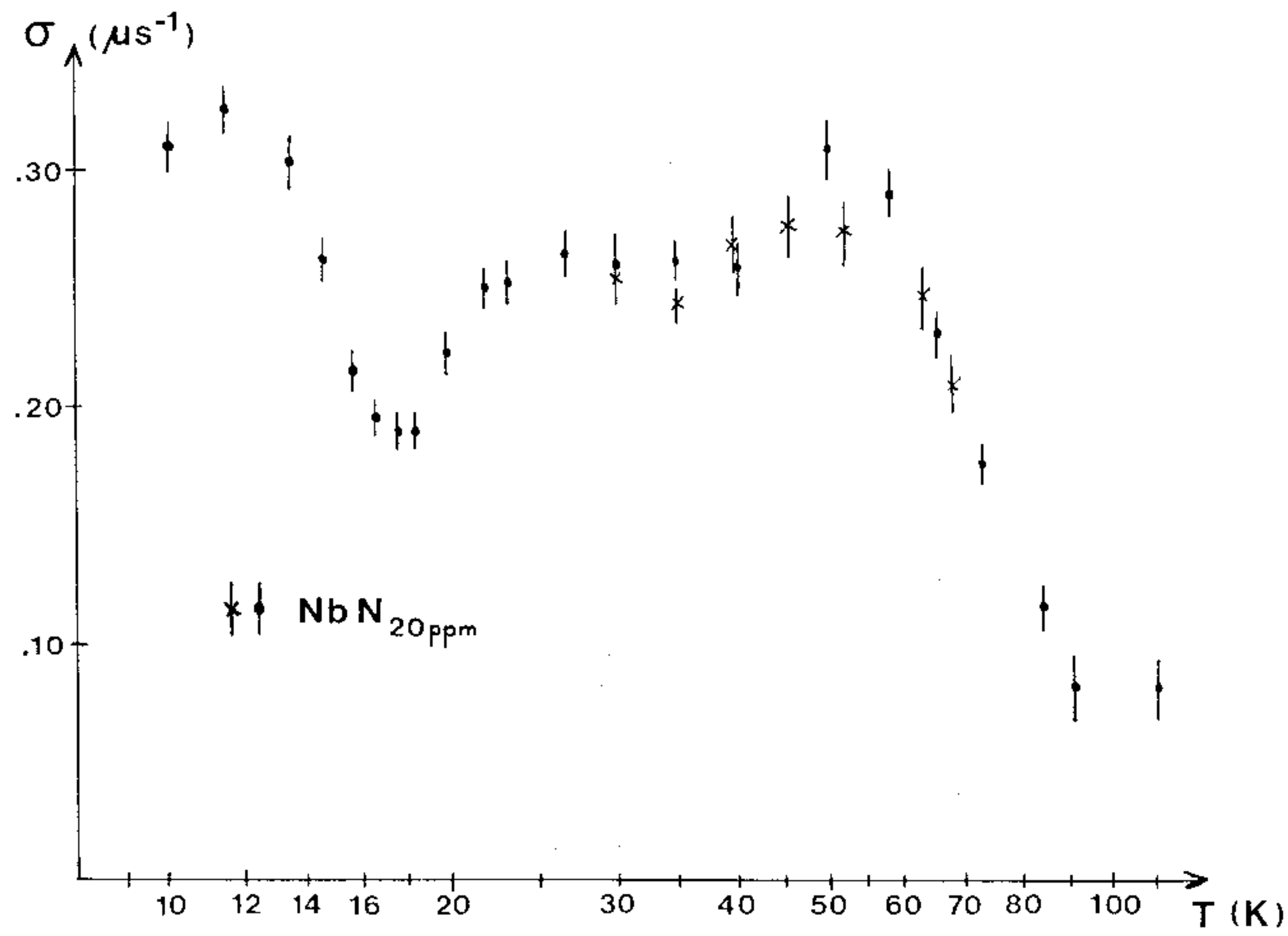

Fig. 2a

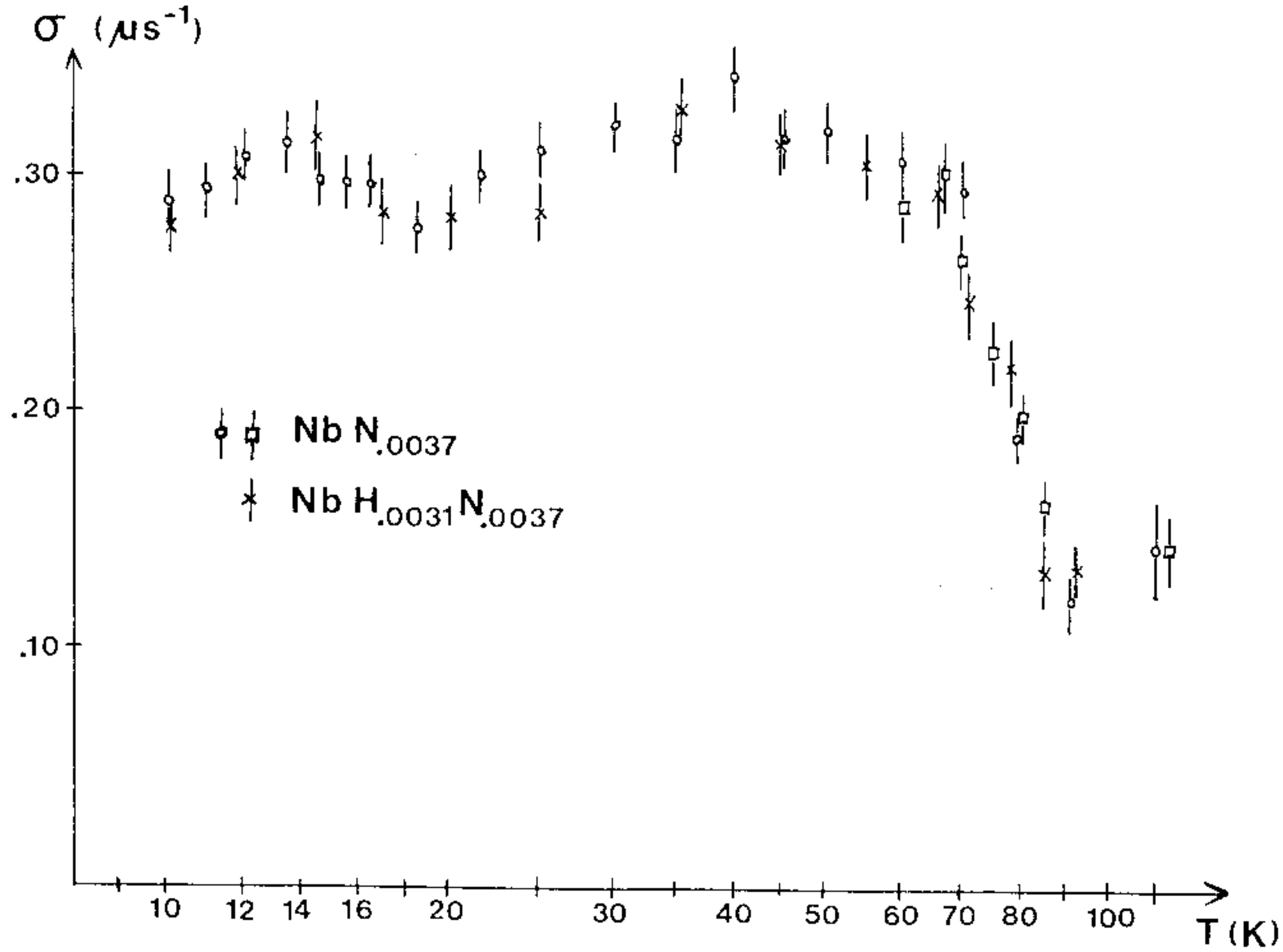
σ (μs⁻¹)
.30
.20
.10
Nb N.0037
Nb H.0031N.0037
10
12
14
16
20
30
40
50
60
70
80
100
T (K)

Fig. 2b