EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/SCC/77-10
1 June 1977

Progress report of SC 65

O.Hartmann, E.Karlsson, L.O.Norlin and K.Pernestål, University of Uppsala.
M.Borghini and T.O.Niinikoski, CERN.
E.Walker, University of Geneva.

A major part of our beam time up to now has been used to study the behaviour of muons in metals. In the following we review briefly the obtained results and discuss our plans for the immediate future.

I. Studies of the behaviour of muons in metals

It was early realized and pointed out in our proposal (PH.III-75/7) that "the studies of muon precession in ferromagnets" required more knowledge about localization of the muons in metals in general for conclusive results about the magnetism. Practically all our experiments up to now have therefore been performed on nonmagnetic metals posessing large nuclear dipole moments. Such metals are suitable for localization studies by the method first used by Gurevich et. al. (1).
The experiments consist of measurements of precession frequency distributions and shifts of muons as function of temperature and applied magnetic field. The width of the frequency distribution informs us about the jump rates between interstitial sites. The properties of the equilibrium position(s) are derived from measurements on single crystals at a low temperature for which the muon can be assumed to be well localized during its lifetime. The frequency distribution (linewidth) is studied as function of magnetic field (50-2000 Gauss) usually applied parallell to one of the principal axes of the crystal.

Results

1a) Diffusion rates and freezing in of muons in copper and aluminium. These metals have been studied in the temperature range 1-600 K. The muons take up stable octahedral interstitial positions in copper below 100 K, but seem to diffuse freely in aluminium at all temperatures investigated. For details see reference 2.

1b) Quadrupole interactions.
In trying to deduce the stable interstitial position for muons in copper it was found that the linewidth did not change with the orientation of the single crystal in the applied magnetic field (350 Gauss). This was contrary to expectations and gave rise to the finding that the neighbouring nuclei do not react only to the applied magnetic field but also to the electric field gradient (efg) caused by a muon sitting close to them.

It was found that this interaction is essential for the interpretation of μSR-data and the work on copper by the CERN group (2) and the SIN group (3) could be understood after a theoretical treatment by Hartmann (4) of the combined electric and magnetic interaction.

2) Localization of muons in body centred cubic metals of W-type.
The muons have been found to diffuse easily at all temperatures in the alkali metal lithium and at least down to 77K for sodium. However in the transition metals vanadium, niobium and tantalum the muons were found to freeze in at low temperatures (<60K), which for niobium is in contrast to earlier information (5). Our studies of muon localization in niobium (single crystal) is as yet inconclusive because of the high magnetic field necessary to overcome the effect of the efg from the muon. In the low fields ($\lesssim$ 2kGauss) presently available at reasonable homogeneity and stability we only see the start of the decoupling of the nuclear precession. Work has started on vanadium single crystals where 2 kGauss should be sufficient. At the moment it seems that the muons in the b.c.c. metals studied here show linewidths not corresponding to unique interstitial sites. However this has to be studied in more detail in future experiments. Our results so far will be reported at the forthcoming conference on hyperfine interactions in Madison, U.S.A..

3) Muons in semimetals.
A series of experiments on the semimetals arsenic, antimony and bismuth were undertaken in order to get better understanding of the interaction of muons with conduction electrons in metals. These experiments gave a surprising result. In antimony below 140K it was found that the precession frequency increased far more than in all metals investigated so far. The effect which rose to more than one precent of the reference frequency could not be explained as a normal Knight shift which is temperature independent, but indicates that a local electronic moment is formed around the muon. Such muonium formation has been observed in semiconductors (6,7) but never before in metals although the effect has been sought for (8). We have investigated the frequency shift as function of

temperature,applied field and direction of the field with respect hexagonal crystal c-axis.It is strongly anisotropic and the magnitude of the shift suggests that the local moment is fairly extended around the muon site.It is not observed in the two other semimetals and seems to occur only when the quasi bond muonium state has a specific energy with respect to the conduction bands and the Fermi level.The results of this investigation will also be presented at the hyperfine interaction conference in Madison.

II Planned research.

It is evident that muon spin precession studies of solids is gradually developping into a new spectroscopy.It is a spectroscopy of high precision;frequencies can be measured easily to $1:10^4$ and linewidths to better than 5% of their normal values at low temperature. The method is unique in the sense that it allows the study of a "single impurity" problem in a metal without any interference of other impurities of the same kind.The metod is of course not limited to this type of problems,but can be applied to several classes of problems in metal physics.Our experience from the first studies at CERN is that new and surprising results may turn up in almost every experiment.The main lines of our plans for further research are as follows,whith some reservations for "new effects";

1) Further studies of the localization and diffusion of muons in b.c.c. metals. Considering the effect described in I.1.b above it is seen that it requires strong ($\geq$ 5kGauss) and very homogenous applied magnetic fields and good single crystals in order to find out definitely where the stable positions for muons are and whether indeed tunnelling states are formed.Furthermore,the diffusion constants and jump rates at higher temperatures in the b.c.c. metals should be determined better.At present there is no theoretical explanation of the large difference (10^3-10^4) in diffusion coefficient (pre-exponential factor) between protons and positive muons in the same metal.

In vanadium we have found anomalies in the temperature dependence of the linewidth between 50K and 100K.One suggestion is that muons diffuse to imperfections in the lattice where they are trapped strongly.This effect must be investigated more carefully.

These experiments are run in collaboration with Dr E.Walker at the University of Geneva.

2) Fast diffusion in aluminium and lithium.

Some light metals allow muons to diffuse easily even at very low temperatures.The reason for that is not well understood and we are preparing samples for further investigation of this effect.

3) Ferromagnets.

The interest in ferromagnetic materials will be reviewed when more becomes known about location and diffusion of muons,partcu-larily in b.c.c. metals.A few ferromagnetic samples have been prepared.Contacts have been taken with Grenoble (Dr Chappert) for exchange of samples of intermetallic rare-earth iron type. However for the studies of ferromagnets several improvements of the experimental conditions are necessary;

a) It remains to optimize the beam and detector arrangement to allow for 0^{o}-detection.In such a geometry unpolarized ferromagnetic samples can be investigated.The present difficulties come from the large positron contamination of the C-beam.

b) The use of a solenoid instead of the electromagnet would im-mediately double the solid angle accessible for detection of decay positrons when the cryostat is used.It would also give a more homogeneous field to ferromagnetic samples and allow for application of longitudinal magnetic fields.

Finally it should be stressed that there is a minimum develop-ment necessary for the μSR experiments to survive at CERN over the next few years.Some of the improvements we think has to be done by CERN since a small group like ours (Uppsala) does not have the economical power to carry through major improvements.

III Request for beam time.

For the rest of the year 1977 we would like to use 45 shifts of beam time in sharing mode for the above suggested experiments.

References:

1) I.I.Gurevich, E.A.Meleshko, I.A.Muratova, B.A.Nikolsky, V.S.Roganov, V.I.Selivanov and B.V.Sokolov. Phys.Lett. 40A (1972) 143.

2) O.Hartmann, E.Karlsson, K.Pernestål, M.Borghini, T.O.Niinikoski and L-O.Norlin. Phys.Lett. 61A (1977) 141.

3) M.Camani, F.N.Gygax, W.Rüegg, A.Schenck and H.Schilling. (submitted to Phys.Rev.Lett.)

4) O.Hartmann. (Available as a CERN preprint. Submitted to Phys. Rev.Lett.)

5) A.T.Fiory, D.E.Murnick, M.Leventhal and W.J.Kossler. Phys.Rev.Lett. 33 (1974) 969.

6) I.I.Gurevich, I.G.Ivanter, E.A.Meleshko, B.A.Nikolsky, V.S.Roganov, V.I.Selivanov, V.P.Smilga, B.V.Sokolov and V.D.Sheslakov. Zh.Eksp.Teor.Fiz. 60 (1971) 471.

7) K.M.Crove, R.F.Johnson, J.H.Brewer, F.N.Gygax, D.G.Fleming and A.Schenck. Bull.Am.Phys.Soc. 17 (1972) 594.

8) V.G.Grebinnik, I.I.Gurevich, V.A.Zhukov, I.G.Ivanter, A.P.Manych, B.A.Nikolskii, V.I.Selivanov and V.A.Suetin. Zh.Eksp.Teor.Fiz. 23 (1976) 11.