

M E M O R A N D U M

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To/A : The SC-committee

From/De : Erik Karlsson, EP, representing the CERN μ SR collaboration

Subject/: μ SR-program around 1980 (requested in connection with
Objet memorandum SCC/78-11)

Introduction

In a memorandum to the PS and SC committees, April 12, 1978 (CERN SCC/78-11) we discussed the need of support from the EP Division, especially concerning personnel and equipment for introduction of a new detection technique. This equipment is meant to be used as a common facility for the μ SR-collaboration (which is, at present, an Uppsala-Parma-Jülich-Geneva-Grenoble group, exploiting μ SR for different applications but using essentially the same instrumentation). In the hope that the SC-committee will support the requests from the collaboration, we are now presenting an outline of the research program for the next few years. In those cases where it will be found necessary we will later send in proposals for those experiments, as separate projects or as addenda to existing projects.

Research program

The first few years' work with the new method has raised several fundamental questions in solid state physics and chemistry. The problem in solid state physics are connected to the description of impurity states in general and are therefore of relevance for a large number of applications. It appears that the positive muon, when introduced in a solid, provides an exceptionally simple impurity problem, having just one unit of electric charge and no electron core. Still the theoretical treatment is -at present- not capable of describing such a system satisfactorily and many more data, for various host materials and under varying external conditions, are necessary to provide a general basis for such treatments.

The main problems to be studied during the next few years fall in the following categories:

Solid systems

(a) The localization problem

We do not yet know to what extent the positive muon can be considered as a localized particle in a metal. At low temperatures it may tunnel between potential minima at a few adjacent sites or it may even be propagating through the lattice like on electrons in a band state. The extension of the muon wave-function in different structures and its dependance on

temperature and crystal purity will be investigated by careful analysis of the muon spin depolarization rate. The necessary high purity starting materials of certain f.c.c. and b.c.c. metals are now becoming available to us. They will be doped with selected sets of impurity atoms in order to look for changes in the localization.

This problem is closely related to the problem of hydrogen impurities, but the wave-mechanical nature of the particle should give more pronounced effects in the case of muons because of their smaller mass.

(b) The diffusion problem

The description of the diffusion of an interstitial particle can be based on classical thermodynamics (the Arrhenius law) or other models taking coherent -see above- or incoherent tunneling into account. For muons as well as for protons the latter corrections should change the temperature dependence. Even in the purely classical limit there will, however, be large and easily observable effects of trapping at certain impurities.

It is our intention to continue the trapping studies in the intermediate temperature range (10-200K) in order to see which impurities that provide traps for muons (and probably also for hydrogen) in some important metals and alloys.

(c) The local electronic structure

It has been found that the local electronic structure around a muon in a solid depends sensitively on the density of conduction electrons: in insulators and certain semi-conductors a free muonium-like state is formed, while in good conductors the muon charge is screened off by (unbound) conduction electrons within a short distance. In semi-metals the situation seems to be somewhere in between, with tendencies toward bound state formation.

In metals the local electronics structure gives rise to a small shift of the local magnetic field (Knight shift) and modifies also the potential well in which the muon will find itself when placed in an interstitial site in a lattice. The electronic structure of the host material and the form of the screening charge cloud are therefore determining factors not only for the local magnetic field but also for the activation energies and heat of solutions of the hydrogen-like particles. We intend to study the effect of conduction electron density in certain non-magnetic metals and semi-metals by selecting some disordered alloy systems with a large mixing range. Similar studies will probably also be of interest with certain systems of low free electron density. Also interesting is the local electronic structure at sites close to trapping centers.

For ordered magnetic materials the electronic structure gives rise to a strong magnetic hyperfine field because of the spin polarization of the local electrons at the muonic site and to a field from electronic dipoles localized on neighbouring sites. This polarization gives further information on the character of the screening electrons, and perhaps ultimately on the details of the electronic structure in the host metal itself.

We intend to study some simple magnetic systems where this information can be correlated with other magnetic data, such as neutron diffraction results and hyperfine fields at the host nuclei. It is especially interesting to study the spatial correlation of the spin polarization close to the magnetic transition temperatures. Because of its characteristic time-window, the μ SR technique should then be able to provide unique information.

The amorphous ferromagnets form another class of magnetic materials where more information might also be gained by the μ SR method.

Liquid and gaseous systems

The muon bound states in molecules of biological interest will be subject to continued studies. The planned improvements may allow us to work with smaller quantities and thus more rare or more pure substances, for instance polynucleotides and DNA models. It is also important that even very small muonium fractions, which often appear in biological systems can now be studied because of the improved signal to noise ratios.

As for the samples in gaseous form we will however still be unable to apply the method, unless we get access to a low momentum muon beam in one form or another.

The planned technical improvements

The advantages with the wire chamber detection techniques have been discussed in detail in the earlier memorandum. Essentially, they consist of (1) an improved signal to background control and (2) an increase in the acceptable counting rate due to space and time selection of events. For the work in moderately high magnetic fields the wire chambers must be built into a specially constructed Helmholtz coil system, which is also being designed at CERN. The whole assembly can be considered as one instrument, a μ SR spectrometer. Since the complete system will be a relatively complex one we shall need continuous support as regards technical personnel.

Final remarks

Details of the planned experiments (exact statement of targets, measuring times etc) cannot be given at the present stage, since they must be adjusted to the development of the field during 1979. The problems studied will be selected in such a way that the results will not become obsolete if Arizona type beams will become available within the next few years at other laboratories. If we should be able to use such beams ourselves in the future, the present construction can be carried over with relatively small modifications.

For the μ SR collaboration


Erik Karlsson