MEETINGS AND CONFERENCES

μSR-83 conference in Japan

Yu. P. Dobretsov and S. P. Kruglov

Usp. Fiz. Nauk **142**, 527–529 (March 1984)

The Third International Conference on the Study of Matter by the Method of Muon Spin Rotation and Related Problems was held on 18–20 Arpil 1983 in Shimoda, Japan.

The conference was organized by the Meson Scientific Laboratory, directed by Prof. T. Yamazaki, at the University of Tokyo.

The method of muon spin rotation, which is briefly referred to as μSR, is based on two phenomena. The first is the asymmetry of the angular distribution of electrons (positrons) in muon decay $\mu^{\pm} \rightarrow e^{+}\nu\nu$ relative to the muon spin, characterized by the parameter $a = a_0P$, where P is the degree of polarization of the muon at the time of its decay and $a_0 = 0.33$. The second phenomenon is the precession of the muon spin and the concomitant precession of the angular distribution of the electrons (positrons) in a transverse, relative to the muon spin, external magnetic field. In the experiment the dependence of the number of electrons (positrons) produced by the decay reaction is measured as a function of time. for $P \neq 0$ this dependence is modulated with a frequency ω_μ, equal to the frequency of precession of the magnetic moment of a free muon, and the amplitude of modulation is $A \sim P$. The interaction of the magnetic moment and spin of the muon with the medium changes the precession frequency and the modulation amplitude. The order of magnitude of the time interval within which it is possible to study the dynamics of the interaction of the muon and the medium by the μSR method is determined by the lifetime of the muon $\tau_\mu (\tau_{\mu^+} \approx 2\mu s, \tau_{\mu^-} \approx 1 - 2\ \mu s)$ and by the resolution of the apparatus.

The μSR method is described in greater detail in a review by Yu. M. Belousov, V. N. Gorelkin, *et al.* in Usp. Fiz. Nauk **129**, 3 (1979) [Sov. Phys. Usp. **22**, 679 (1979)].

In semiconductors and insulators a positively charged muon forms a muonium atom ($Mu = \mu^{+}e^{-}$), which is a light isotope of hydrogen. The study of the dynamics of the behavivor of muonium in matter gives information on the behavior of hydrogen.A negative muon stopped in matter is captured by an atom of the matter and within a short time ($< 10^{-10}$ s) ends up in the K shell corresponding to its mass. The small size of the shell leads to the fact that the electronic shell of an atom with atomic number $Z - 1$ (a "mu-nucleonic atom") forms on the mesoatom (μ^{-} + nucleus Z). This permits studying the interaction of a tagged impurity $Z - 1$ atom with its surroundings.

The muon spin rotation method was first used in our country to investigate matter in the 1970s. During the same period Soviet theoreticians began to develop the theory of the method. In recent years, investigations of matter by the μSR method have been developing intensively.

At the μSR-83 conference in Japan 130 reports (primarily on experimental work) were presented on work performed at the meson factories SIN (Switzerland), TRIUMF (Canada), LAMPF (USA), as well as on the synchrocyclotron at CERN and in the Meson Laboratory at the KEK Accelerator (Japan). From our country, five reports were presented concerning the investigation of semiconductors, the study of diffusion and phase transitions into the antiferromagnetic state, the investigation of mu-nucleonic atoms, as well as the results of μSR investigations in the mu-meson channel of the synchrocyclotron at the Leningrad Institute of Nuclear Physics of the USSR Academy of Sciences (LINP). The conference took place in Shimoda approximately 170 km from Tokyo in a hotel which was well-equippped for the accommodation of small conferences. Approximately 200 scientists, half of whom were physicists form European countries, the USA, Canada, and China, participated in the meetings. The μSR conference was very representative; essentially all the well-known specialists in this field participated.

BASIC PROBLEMS EXAMINED AT THE μSR CONFERENCE

1. Diffusion and localization of muons in matter. Quantum diffusion. Capture of μ^{+} mesons by impurities and defects and freeing of muons from these traps.

2. Local fields acting on μ^{+} and μ^{-} mesons; the muon as an indicator of local magnetic fields (investigation of ferromagnets and disordered magnets of the spin- and metallic-glass type).

3. Muonium-like states in solids (μ^{+}, normal muonium, anomalous muonium in semiconductors and insulators).

4. Muonium chemistry.

5. Hyperfine interaction in free muonium and in mu-nucleonic atoms.

6. Related physical problems:

a) $\pi^{+}/\mu^{+}/e^{+}$ channelling;

b) the problem of the electroweak interaction and measurement of muon polarization;

c) new developments in instrumentation for μSR experimenters.

Interesting reports on the study of normal and anomalous muonium were made by Wedinger (FRG) and Patterson (Switzerland). These studies supplement the results of investigations of the (Mu) and (Mu)* states in silicon irradiated by neutrons, performed at LINP and reported by S. P. Kruglov. It has now been proved that anomalous muonium (Mu)* is a bound system situated at a distance of 1.6Å from the silicon atom with a $\langle 111 \rangle$ symmetry axis. Normal muonium (Mu) diffuses rapidly in matter. Both normal and anomalous muonium atoms form initially (at the time the μ^{+} meson is stopped). The (Mu) and (Mu)* atoms exist as Coulomb systems in a wide temperature range. It turns out, however, that

 0038-5670/84/030228-02$01.80

they can be observed by means of the hyperfine interaction only in a limited temperature range ($T < 140$ K for (Mu)* and $T \leqslant 300$ K for (Mu)).

Muon spin rotation investigations of irradiated metals with different concentrations of radiation-induced defects are interesting. Physicists in the FRG were able to observe for the first time the capture of muons by irradiation-induced vacancies and by vacancy-impurity pairs. In iron alloys different precession frequencies are observed in each of these states.

A large number of reports concerned the investigation of quantum diffusion in Al, Nb, Cu, and Bi. The reports were made by scientists from Switzerland, Canada, the FRG, and the USSR. There is now no doubt that quantum diffusion exists in pure metals at temperatures $T < 4$ K. There are, however, several theoretical approaches to the explanation of the observed experimental data.

A number of reports concerned new possibilities of using negative muons in the μSR method. Yu. P. Dobretsov reviewed the experimental situation with the formation and observation of free mu-nucleonic atoms. Ort (FRG) reported on the results of measurements of the hyperfine (hf) splitting in mu-nucleonic hydrogen ($\mu H = \mu^{-4}$He1e$^-$), which from the point of view of hf splitting is analogous to muonium. The comparison of hf splitting in both atoms is of great interest from the point of view of checking QED and the identity of the electromagnetic interactions of $\mu^{\pm}$ mesons and measuring the magnetic moment and mass of the μ^- meson by yet another independent method.

The precession of the μ^- meson in the ferromagnetic material (Ni) has been observed for the first time with the μSR method and the internal magnetic field has been measured. The mesoatom $\mu^- Z$ is a pseudonucleus with charge $Z - 1$, which has a specific charge and magnetic distribution and must have a very different hf interaction with electrons as compared with the nucleus of a $Z - 1$ atom in the same material. The observation of hf anomalies is a new method for determining the distribution of the electronic spin density near a nucleus. The work was performed at SIN and was presented by K. Nagamine (Japan).

J. Brewer (Canada) presented the results of observations of the precession of the spin of the μ^- muon in mesoatoms with nonzero nuclear spin. The work was performed for the nuclei Li, Be, Cl, Na, K, P, Al, Ca, V, Nb, Co, and Cu. The states $F^{\pm} = i_n \pm (1/2)$, where i_n and 1/2 are the spins of the nucleus and of the muon, respectively, as well as the transitions $F^+ \rightarrow F^-$ were observed.

Among the results of experiments which are not directly related with μSR, the measurement of the parameter η for $\mu \rightarrow e$ decay, presented by Crowe (USA), is of great interest. The new limit is $\eta < 0.03$, which is approximately an order of magnitude smaller than the previous result.

The discussion of methodological problems showed that the technique and apparatus used abroad for μSR investigations is sophisticated and is constantly being improved. The development of cryostats for work at temperatures down to 0.05 K and superconducting Helmholtz coils in order to obtain magnetic fields up to 50 kG is especially important in order to maintain a high level of scientific research in the USSR.

The problems of using pulsed beams of muons for conducting μSR investigations were discussed at the conference. The reports by Japanese physicists and Dr. Cox (England) should be studied very carefully in connection with equipping the meson factory in Moscow. The methods developed by Japanese physicists do not involve any fundamental restrictions on the intensity of the muon beam.

The conference proceedings will be published in a special issue of the journal "Hyperfine Interaction" at the end of 1983.

At a meeting of the international committee which organized the conference it was decided that the next conference should be held in 1986.

At the end of the μSR-83 conference the participants visited the laboratory of the meson factory at the KEK accelerator (UTMSL). Part of proton beam from a 500-MeV proton synchrotron, which is an injector for the KEK accelerator (the proton energy is 12 GeV), was used to obtain the beam of muons. The laboratory is equipped with a superconducting solenoid, which focuses the muon beam. Four thousand hours per year are devoted to μSR experiments. There are three simultaneously functioning muon beams: a beam of surface muons with an energy of ~ 4 MeV; a beam of separated muons with momentum ~ 100 MeV/c; and, a beam of "unfiltered" muons with momentum ~ 200 MeV/c. There are five μSR installations in the laboratory. The installation with superconducting Helmholtz coils, which permits performing investigations in longitudinal magnetic fields of up to 40 kG, is especially interesting. The investigations at the laboratory are being conducted over a very wide front with both μ^+ and μ^- mesons being used (investigations of diffusion, magnetism, spin glasses, μSR in ferromagnets, and chemical compounds). At the μSR conference Japanese physicists presented more than 20 reports on the results of their investigations. The conference was well organized and proceeded in accordance with the program.

Translated by M. E. Alferieff