Low Temperature Laboratory

ANNUAL REPORT 1970

I N M E M O R I A M

Mr. Sulo Virtanen, chief technician to the laboratory, suffered a fatal heart attack on Febr. 15, 1970. Mr. Virtanen showed truly exceptional devotion to his work and could always be counted on in an emergency. His memory will remain fresh in the minds of all those of us who have had the pleasure of working with him.

Low Temperature Laboratory
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A N N U A L R E P O R T 1 9 7 0

1. GENERAL INFORMATION

Research in this laboratory, which was established in 1965, is mainly in the field of solid state physics at low and very low temperatures. Technical projects related to cryogenics are also important. Most units of the laboratory are located in the basement floor of the Technical Physics Building on the campus of the Technical University, about 9 kms west of downtown Helsinki.

2. PERSONNEL

O.V. Lounasmaa (Research Professor of the Finnish Academy);
S.T. Stenholm (Acting Professor);
M. Luukkala (Associate Professor);
N.E. Phillips (Visiting Professor, University of California, Berkeley);
G.R. Pickett (D.Phil., research fellow, University of Lancaster);

T.E. Katila (D.Tech., senior research fellow);

Yu.D. Anufriyev (Ph.D., visiting research fellow, Institute for Physical Problems, Moscow);

P. Reivari (D.Tech., senior research fellow);

Marja Holmström (Lic.Phil., laboratory engineer);

P.E. Gregers-Hansen (Senior graduate student);

M.I. Aalto, T.A. Alvesalo, P.M. Berglund, H.K. Collan, G.J. Ehnholm, T.L. Ericsson, R.G. Gylling, M.A. Hattunen, T.A. Heikkilä, S.T. Islander, J. Ivarsson, M.F. Krusius, T.O. Niinikoski, O.F. Sarlin, J.I. Surakka R.P. Søvik, V.K. Typpi (graduate students);

P. Buch Lund, M.T. Hirvonen, R.M. Nieminen, K.O. Nores, M.A. Paalanen, R.R. Salomaa, M.J. Valo, M.C. Veuro (undergraduate students);

P.R. Piekkola, P.K. Poukka, N.I. Vehviläinen, S.A. Virtanen (senior technicians);

E.J. Ahola, Hilkka Hänninen, S.I. Kaivola, K.J. Lingman, E. Mattsson, E.O. Turtiainen (technicians);

1 1/2 secretaries.

Four of the above mentioned graduate students, Ericsson (University of Uppsala), Gregers-Hansen (University of Copenhagen), Ivarsson (Chalmers University of Technology, Gothenburg), and Søvik (University of Oslo), spent the Academic year 1970-71 in the laboratory with scholarships from the Nordic Cultural Foundation.

Prof. O.V. Lounasmaa was appointed on June 17, 1970 Research Professor of the Finnish Academy for the five year period beginning on September 1, 1970.

3. ACADEMIC DEGREES

The laboratory personnel has obtained the following Academic Degrees during 1970:

Doctor of Technology: T.E. Katila, P. Reivari

Diploma Engineer: T.A. Alvesalo M.A. Hattunen, T.A. Heikkilä, J.I. Surakka, V.K. Typpi

4. RESEARCH PROJECTS

4.1. Mössbauer experiments (Katila, Hirvonen, Typpi)

This apparatus, utilizing the $^3He/^4He$ dilution refrigeration principle, enables sources or absorbers to be cooled to a minimum temperature of 0.03 K. An investigation of rare earth magnetism is currently the main project. Several Tm^{3+} compounds with crystal field singlet ground state have been investigated. Exchange induced ordering of a singlet crystal state was observed in $Tm_2(SO_4)_3 \cdot 8H_2O$. Gd^{3+} compounds have been used to study the magnetic properties of an S-state ion in isomorphous rare earth compounds. Nuclear polarization is employed for the Mössbauer effect thermometry, hyperfine interactions at the source nuclei, and nuclear transitions. The sign and magnitude of the hyperfine field at ^{57}Co nuclei has been measured e.g. in dilute alloys Co-Pd, Co-Pt and Co-Fe. The γ-transitions of ^{169}Er and ^{197}Pt have been studied, using nuclear polarization to determine their mixing ratios. Relaxation of Fe^{3+} spins at low temperatures has been seen e.g. in $K_3Fe(CN)_6$. Several experimental problems connected with measuring techniques are also studied.

4.2. ^3He cryostat (Islander)

The specific heat C_p of GdF_3, Re, $Fe_{49,5}Rh_{45,5}Ir_{5,0}$, $Fe_{49,1}Rh_{50,9}$, $Fe_{51,8}Rh_{48,2}$ and $Fe_{52}Rh_{48}$ at $T = 0.6$ to 2.5 K has been measured. The analysis of ^3He - ^4He mixtures' specific heat data has been completed. The apparatus used for mixture investigations has been calibrated by making specific heat measurements on pure ^3He at three different degrees of filling of the calorimeter. This will ensure the possibility of reliable comparison with earlier experiments and those to come in future. A program to measure specific heat of isotopically pure metals at temperatures 0.5 to 2.0 K is being arranged. The continuation of these measurements to the 100 mK region, involving the replacement of the ^3He cryostat by a dilution machine, is planned.

4.3. Nuclear specific heats (Pickett, Gregers-Hansen, Krusius)

Since 1967 hyperfine interactions have been studied in the rare earth metals and the semimetals with calorimetric measurements using an adiabatic demagnetization cryostat. In the previous years the nuclear specific heats of nine rare earths were measured in the temperature range 0.02 - 0.5 K. As a continuation of these measurements the magnetic ordering properties at the lowest temperatures of polychrystalline praseodymium and neodymium were investigated by measuring the nuclear specific heat in external magnetic fields. The hyperfine field in praseodymium showed strong and continuous polarizability by the external field and the phenomenon of hyperfine field enhanced nuclear cooling was demonstrated. In neodymium, however, no polarization was achieved with the magnetic fields available of 20 kilogauss and less.

The investigations of the nuclear quadrupole interactions in the semimetals were continued with measurements on arsenic and tellurium doped bismuth. Earlier it had been found that the extremely low free carrier density in bismuth caused the nuclear spin-lattice relaxation time to be long enough to decouple the quadrupole interaction from the specific heat in a practical experiment. This suggested the use of some dopant like the electron donor tellurium for improving spin-lattice relaxation. In addition to the increase in spin-lattice coupling with the tellurium content the experiments also revealed a large linear increase in the electric field gradient. In order to compare nuclear specific heat in the semimetals and in a good metallic conductor the quadrupole interaction in rhenium was measured. Due to its much larger magnitude the sign of the interaction could also be resolved in this case.

The heat capacity measurements were finished in September and the cryostat was used for Pomeranchuk cooling experiments thereafter.

4.4. Experiments on Pomeranchuk cooling (Phillips, Anufriyev, Buch Lund, Nores, Valo, Veuro)

A Pomeranchuk cooling stage has been constructed and added to the previuos adiabatic demagnetization cryostat. The

old CMN temperature measuring system has been replaced by NMR apparatus using platinum as signal source material. In preliminary experiments Pomeranchuk cooling and platinum NMR signal have been observed. Further investigations of the present system are going on with experiments on the magnetic properties of ^{3}He as the objective.

4.5. Experiments with nuclear cooling (Lounasmaa, Aalto, Berglund, Collan, Ehnholm, Gylling, Paalanen)

A cryostat has been constructed in which, for the first time, dilution refrigeration and nuclear cooling operate in series. Preliminary experiments have resulted in an equilibrium temperature of 0.52 mK in the copper nuclear stage. This is the lowest lattice and conduction electron temperature ever achieved. The nuclear stage has remained below 1 mK for more than 6 hours. Measurements on spin-lattice relaxation and thermal conductivity of copper have been carried out in the 1 mK - 10 mK region. Effort has also been put in developing thermometry suitable for the mK temperature region, including nuclear orientation, pulsed NMR- and continuous wave NMR-thermometry.

The apparatus is presently being prepared for a research program investigating the Kapitza resistance between liquid ^{3}He and solids in the mK region.

4.6. Ultrasonic wave interactions and phonons (Luukkala, Hattunen, Surakka)

At present the main interest focuses on acoustic surface waves and their nonlinear interactions. Convolution, correlation and time inversion using parametric interactions of 100 Mhz surface waves are currently being investigated. The photolitographic fabrication of interdigital surface wave transducers has also got started. Critical angle reflectivity measurements in liquid-metal boundaries have also been performed where we have found a new, leaky-mode propagation, corresponding to a complex wave vector. Several related technical projects are also in progress.

4.7. Theoretical work (Stenholm, Hirvonen, Salomaa)

Studies are pursued on the further development of W.E. Lamb's semiclassical laser theory extended to large intensities (Stenholm, Salomaa) and on the experimental consequences of relaxation phenomena in Mössbauer spectra (Stenholm, Hirvonen). In addition, M. Vuorio (Research Institute for Theoretical Physics, University of Helsinki) is investigating, in collaboration with our laboratory, the Kapitza thermal boundary resistance between ^{3}He and a magnetic substance. This work is of practical importance for measurements of the properties of liquid ^{3}He at ultralow temperature, as planned for the nuclear cooling cryostat.

4.8. Technical projects (Sarlin)

Many technical projects are pursued, partly in collaboration with Finnish industry. These include design and construction of complete dilution cryostats for other universities as a part of joint research projects and helium leak testing of nuclear power station components made by Finnish industry.

5. VISITS AND COLLABORATION WITH OTHER LABORATORIES

The following persons have participated, during 1970, in our research projects:

Dr. J. Toth (Central Research Institute for Physics, Budapest). ^{3}He cryostat (1 1/2 months);

Dr. E. Seidel (Technische Hochschule, Munich). Mössbauer effect research (2 months);

Dr. F. Wagner (Technische Hochschule, Munich). Mössbauer effect research (2 months);

Dr. S.G. Lipson (Technion, Haifa). (1 month);

Dr. D. Novák (Institute for Nuclear Research, Debrecen). (2 months);

Dr. J. Sawicki (Jagellonian University, Cracow). Mössbauer effect research (2 months).

The following persons have made short visits to our laboratory for the purpose of giving seminars and participating in

scientific discussions:

Academician N.N. Bogoliubov (Nuclear Research Institute, Dubna);

Prof. J.C. Wheatley (University of California, La Jolla);

Prof. Stig Lundqvist (Chalmers Tekniska Högskola, Göteborg);

Prof. S.S. Hanna (Stanford University);

Prof. P. Kienle (Technische Hochschule, Munich);

Prof. B.P. Gregory Director General, Cern);

Prof. L. Reatto (University of Parma);

Dr. A. Yokosawa (Argonne National Laboratory);

Dr. J. Vermeulen (Cern, Geneve);

Dr. J. Ketterson (Argonne National Laboratory);

Dr. R.L. Cohen (Bell Telephone Laboratories, Murray Hill);

Prof. D. Pines (University of Illinois).

Prof. O.V. Lounasmaa was working as a visiting scientist at the University of California (San Diego) on January 2-15, 1970, and at the Argonne National Laboratory on January 19-24, 1970. He has given the following seminars: "The Pomeranchuk Method of Cooling", on January 29, 1970, at the Institute Laue-Langevin in Grenoble; "Recent Experiments with Nuclear Cooling", on October 22, 1970, at the Free University of Berlin; on October 26, 1970, at the University of Louvain; on November 23, 1970, at the University of Uppsala; on November 24, 1970, at the University of Copenhagen; on November 25, 1970, at the University of Leiden; and on November 26, 1970, at the University of Amsterdam.

The laboratory personnel made a group visit in June 1970 to the A.F. Ioffe Physico-Technical Institute, Leningrad.

About 30 physicists from developing countries, who participated in the International Seminar of Physics in Uppsala, visited the Low Temperature Laboratory in September 1970.

Some of our Mössbauer effect research has been done in collaboration with Prof. R.L. Mössbauer's laboratory at the Technische Hochschule, Munich (Dr. F. Wagner and Dr. E. Seidel).

6. PARTICIPATION IN SUMMER SCHOOLS AND CONFERENCES

VI Mössbauer Effect Methodology Congress, Chicago, January 25, 1970: O.V. Lounasmaa.

The Annual Meeting of the American Physical Society, Chicago, January 26, 1970: O.V. Lounasmaa.

Ultralow Temperature Symposium, NRL, Washington, April 23-24, 1970: R.G. Gylling, paper on "Nuclear cooling combined with dilution refrigeration".

Third International Cryogenic Engineering Conference, Berlin, May 25-27, 1970: O.V. Lounasmaa, paper on "Nuclear cooling combined with dilution refrigeration".

Europian Physical Society: Summer School in Low Temperature Physics, Amsterdam, June 22 - July 4, 1970: T.A. Alvesalo, P.M. Berglund, M.T. Hirvonen, O.F. Sarlin, V.K. Typpi, H.J. Valo, M.J. Vuorio. A report by Berglund: "Nuclear cooling in Helsinki".

The 4th Nordic Solid State Conference, Turku, August 10-13, 1970: O.V. Lounasmaa; P.M. Berglund; V.K. Typpi, paper on "Mössbauer measurements of some rare earth compounds with a $^3He/^4He$ dilution refrigerator"; S.T. Islander, paper on "Specific heat of liquid $^3He/^4He$ mixtures near the junction of the lambda and phase-separation curves"; M.F. Krusius, papers on "Nuclear heat capacity of the semimetals As, Sb and Bi" and "Magnetic ordering properties of polycrystalline praseodymium and applications to nuclear cooling"; P.E. Gregers-Hansen, paper on "Specific heat of rhenium in the temperature range 0.02 K to 0.4 K"; M.T. Hirvonen, paper on "Hyperfine fields at dilute Fe and Co impurities at Pt and Pd hosts at low temperatures".

The 12th International Conference on Low Temperature Physics, Kyoto, September 4-10, 1970: O.V. Lounasmaa; T.E. Katila, papers on "Mössbauer measurements of some rare earth compounds with a $^3He/^4He$ dilution refrigerator" and "Hyperfine fields at dilute Fe and Co impurities in Pd and Pt hosts at low temperatures"; G.R. Pickett, papers on "Specific heat of liquid $^3He/^4He$ - mixtures near the junction of the lambda and phase-separation curves", "Quadrupole interactions in the semimetals As, Sb and Bi" and "Nuclear heat capacity and nuclear cooling

of metallic praseodymium"; R.G. Gylling, paper on "Nuclear cooling combined with dilution refrigeration".

International Institute of Refrigeration, Commission I Meeting, Tokyo, September 11-12, 1970: G.R. Pickett, paper on "A pulsed nuclear resonance thermometer, and its use to determine the shape correction of a CMN slurry thermometer"; R.G. Gylling, paper on "A powerful dilution refrigerator for nuclear cooling experiments".

1970 International Conference on Magnetism, Grenoble, September 13-19, 1970: S.T. Stenholm; M.F. Krusius, paper on "Magnetic ordering properities of polycrystalline praseodymium and applications to nuclear cooling".

IBM Surface Wave Conference, New York, 1970; M. Luukkala.

7. PUBLICATIONS DURING 1970

D.O. Riska and S. Stenholm, "The Effect of Detuning on the Quantum Theory of an Inhomogeneously Broadened Laser". Journal of Physics A (London) 3, 556 (1970).

H.K. Collan, M.F. Krusius and G.R. Pickett, "Specific Heat of Antimony and Bismuth between 0.03 and 0.8 K". Physical Review B 1, 2888 (1970).

S. Stenholm, "The Principles of Statistical Physics" (in Swedish). Reflecta.

S. Stenholm, "On the Theory of Non-hermitean Operators". Ann. Acad. Sci. Fenn. A VI, 339 (1970).

A.O. Kajaste and T.E. Katila, "Error Signal Analyser for Mössbauer Drivers". Journal of Physics E: Scientific Instruments 3, 934 (1970).

G.J. Ehnholm, T.E. Katila, O.V. Lounasmaa, P. Reivari and G.M. Kalvius, "Mössbauer Study of the β-decay of ^{197}Pt with Oriented Nuclei". Phys. Rev. C 1, 2109 (1970).

G.J. Ehnholm, T.E. Katila, O.V. Lounasmaa, P. Reivari, G. M. Kalvius

and G.K. Shenoy, "Mössbauer Study of Hyperfine Interactions in Divalent Europium Compounds at Ultra Low Temperatures". Z. Physik 235, 289 (1970).

H.K. Collan, T. Heikkilä, M.F. Krusius and G.R. Pickett, "On the Measurement of Small Heat Capacities at Low Temperatures". Cryogenics 10, 389 (1970).

T. Ericsson, M.T. Hirvonen, T.E. Katila and V.K. Typpi, "Hyperfine Fields at Dilute Fe and Co Impurities in a Pt Host below 4.2 K". Solid State Communications 8, 765 (1970).

P.M. Berglund, G.J. Ehnholm, R.G. Gylling, O.V. Lounasmaa and R.P. Sovik, "Nuclear Cooling Combined with Dilution Refrigeration". Proc. 3rd International Cryogenic Engineering Conf., (Berlin 1970), p. 473; Proc. 1970 Ultralow Temperature Symposium, NRL Report 713 (Washington 1970), p.113; Proc. 12th International Conf. on Low Temperature Physics, (Kyoto 1970).

M.I. Aalto, T.A. Heikkilä, M.F. Krusius and G.R. Pickett, "A Pulsed Nuclear Resonance Thermometer with Digital Readout". Proc. Meeting of the International Institute of Refrigeration, Comm. I, (Tokyo 1970), p. 33.

F.E. Wagner, W. Pozel and T.E. Katila, "Zero Point Spin Deviation in Antiferromagnetic $(NH_4)_2\ IrCl_6$". Phys. Letters 33A, 83 (1970).

Yrjö Collan and Heikki Collan, "Interpretation of Serial Sections". Zeitschrift für wissenschaftliche Mikroskopie und mikroskopische Technik 70, 156 (1970).

P.E. Gregers-Hansen, M.F. Krusius and G.R. Pickett, "Sign of the Nuclear Quadrupole Interaction in Rhenium Metal". (to be published).

G.J. Ehnholm and R.G. Gylling, "A Dilution Refrigerator with Large Cooling Power". Cryogenics 11, 39 (1971).

H.K. Collan, P.E. Gregers-Hansen, M.F. Krusius and G.R. Pickett, "Quadrupole Interactions in the Semimetals As, Sb and Bi." Proc.

12th International Conf. on Low Temperature Physics (Kyoto 1970).

P.E. Gregers-Hansen, M.F. Krusius and G.R. Pickett, "Nuclear Heat Capacity and Nuclear Cooling of Metallic Praseodymium". Proc. 12th International Conf. on Low Temperature Physics (Kyoto 1970).

P.M. Berglund, G.J. Ehnholm, R.G. Gylling, O.V. Lounasmaa and R.P. Søvik, "A Powerful Dilution Refrigerator for Nuclear Cooling Experiments". Proc. Meeting of the International Institute of Refrigeration, Comm. I (Tokyo 1970).

T.E. Katila, E.R. Seidel, G. Wortmann and R.L. Mössbauer, "Magnetic Properties of Thulium Salts at Very Low Temperatures". Solid State Comm. 8, 1025 (1970).

P. Reivari, "Ultrasonic and Polarization Measurements with the Mössbauer Effect". Thesis for the Degree of Doctor of Technology (1970), Technical University of Helsinki.

T.E. Katila, "Mössbauer Experiments with a $^3He/^4He$ Dilution Refrigerator". Thesis for the Degree of Doctor of Technology (1970), Technical University of Helsinki.

O.V. Lounasmaa, R.T. Johnson, R. Rosenbaum, O.G. Symko and J.C. Wheatley, "Low Temperature Melting Curve of ^3He". J. Low Temperature Phys. 2, 403 (1970).

S. Stenholm, "Pressure Effects in a High-Intensity Gas Laser". Phys. Rev. A 2, 2089 (1970).

S. Stenholm, "Exact Solution of a Case of Semiclassical Laser Equations". Phys. Rev. B1, 15 (1970).

D.O. Riska and S. Stenholm, "On the Quantum Theory of a Laser with Inhomogeneous Broadening". J. Phys. A (London) 3, 189 (1970).

P. Jauho, D.O. Riska and S. Stenholm, "Approximate Photon Distributions in Lasers." Phys. Lett. 31A, 422 (1970).

S. Stenholm, "Semiclassical Theory of the Gas Laser". To be published in Progress in Quantum Electronics (1970).

M. Luukkala, "On the Surface Corrugation and Surface Wave Propagation in a $LiNbO_3$ Delay Rod". Publications of the Helsinki University of Technology, TKK-F-A128 (1970).

M. Luukkala, "Acoustic Convolution and Correlation Using Nonlinear Interactions of Surface Waves in $LiNbO_3$". Publications of the Helsinki University of Technology, TKK-F-A132 (1970).

G.M. Kalvius, G.K. Shenoy, G.J. Ehnholm, T.E. Katila, O.V. Lounasmaa and P. Reivari, "Quadrupole Moment of the 21.6-keV State of ^{151}Eu". Publications of the Helsinki University of Technology, TKK-F-A103 (1970).

Otaniemi, August 1, 1971

Olli V. Lounasmaa