Low Temperature Laboratory

ANNUAL REPORT 1969

Low Temperature Laboratory
Department of Technical Physics
Technical University of Helsinki
Otaniemi, Finland

A N N U A L R E P O R T 1 9 6 9

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 (Professor);
M. Luukkala (Associate Professor, on leave of absence at Stanford University);
S. Stenholm (Docent, acting Associate Professor);
G.R. Pickett (D.Phil., research fellow);
Marja Holmström (Lic.Phil., laboratory engineer);

P.E. Gregers-Hansen, T.E. Katila, P.Reivari (senior graduate students);

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

T.A. Alvesalo, Mona Grönstrand, M.A. Hattunen, T.A. Heikkilä, M.T. Hirvonen, V.K. Typpi, M.J. Valo (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.

3. ACADEMIC DEGREES

The laboratory personnel has obtained the following Academic Degrees during 1969:

Licentiate of Technology: T.E. Katila.

Diploma Engineer: M.I. Aalto, P.M. Berglund, T.O. Niinikoski, M.J. Vuorio.

4. RESEARCH PROJECTS

4.1. Mössbauer effect research (Katila, Ericsson, Hirvonen, Typpi)

These measurements have been made in a $^{3}He/^{4}He$ dilution refrigerator. Experiments in the entire temperature range from 20 mK to 300 K are possible.

An investigation of rare earth magnetism has been the central project. Several compounds of ^{151}Eu, ^{153}Eu, ^{155}Gd, ^{156}Gd, and ^{169}Tm have been studied. From their Mössbauer spectra information is obtained about hyperfine interactions and, furthermore, the magnetization may be investigated as a function of temperature and the Curie or Néel points can be determined.

At the lowest temperatures nuclear polarization is evident in most spectra. This effect can be used for investigating hyperfine interactions in the source nuclei and for studying the parameters of the nuclear transitions involved. Typical measurements of this type are an investigation of the effective magnetic field at the ^{57}Co in different matrices and a study of the mixing ratio of the vector and scalar terms in forbidden β-decays (^{169}Er, ^{197}Pt).

Nuclear polarization can also be utilized as an absolute thermometer.

Electronic relaxation effects have been investigated in the Mössbauer spectra of several compounds of $^{57}Fe^{3+}$ and $^{169}Tm^{3+}$.

Many purely experimental problems, inherent for Mössbauer research at very low temperatures, have been studied. These include thermal contact, measurement and stabilization of temperature, and development and calibration of drive systems.

4.2. ^{3}He cryostat (Pickett, Islander, Ivarsson, Alvesalo, Grönstrand).

An extensive research project of measuring the specific heat of liquid $^{3}He/^{4}He$ mixtures near the junction of the λ and the phase separation curves has been concluded. High precision data was obtained for the following molar fractions of ^{3}He: 0.530, 0.580, 0.610, 0.640, 0.656, 0.668, 0.671, 0.680, 0.701, and 0.731. The results have yielded valuable information on the thermodynamics of the λ-transition in diluted ^{4}He and also on the form of the energy discontinuity at phase separation. The subject of $^{3}He/^{4}He$ mixtures is of considerable current interest and thus it is important to know the behavior of the specific heat accurately.

Modifications have just been concluded in the cryostat for starting a series of measurements on the specific heat of Gd/Lu alloys between 0.35 and 4 K. Being the last member of the lanthanide group, with a filled 4f electronic shell, Lu is an ideal nonmagnetic host for alloying with other rare earths. It is hoped that the planned measurements will throw light on the magnon contribution to the specific heat as a function of temperature, concentration, and external magnetic field.

4.3. Adiabatic demagnetization cryostat (Pickett, Gregers-Hansen, Reivari, Aalto, Collan, Krusius, Heikkilä, Valo).

A major program of investigating the nuclear specific heats of rare earth metals between 0.02 and 0.5 K is being concluded. The most recent metals studied are Er and Eu.

The data on Er give a hyperfine coupling constant which is lower than that calculated from NMR measurements on Er salts. As our specific heat results on other heavy rare earths have been in good agreement with calculations this discrepency seems interesting.

Measurements on Eu are complicated by the extremely high chemical reactivity of this metal. Distinct from other rare earths which are trivalent, the charge state of Eu ions is +2; this is due to a tendency of producing a half-filled $4f^7$ electronic shell. Our measurements show that owing to the zero orbital angular momentum of a $4f^7$ shell the hyperfine interaction is an order of magnitude less in Eu than in the other rare earths.

A highly improved version of a copper nuclear free precession thermometer has been developed for use in the milli- and microdegree ranges of temperature. Comparisons of the CMN and copper temperature scales have been made down to 8.5 mK. A synchronous detector for this thermometer is under construction;. this device should improve the accuracy to better than 1% in temperature at 10 mK.

Work is in progress for converting the apparatus into a cryostat employing a dilution refrigerator and a Pomeranchuk cooling stage in series.

4.4. Nuclear demagnetization cryostat (Lounasmaa, Berglund, Ehnholm, Gylling, Niinikoski, Søvik).

This project has an ambitious and difficult goal: the construction of a cryostat, employing $^3He/^4He$ dilution refrigeration and nuclear demagnetization in series, for obtaining and maintaining temperatures below 1 mK.

So far most of the units have been built. This includes a vibrationless support for the cryostat, an electrically shielded room, all pumping installations, the ^{3}He gas handling systems, the cryostat itself, the dewars, most of the measuring electronics, and a large superconducting magnet with its power and control units. The dilution refrigerator has been tested and it performed better than expected: the lowest temperature reached was 11 mK and the cooling power at 20 mK was 30 ergs/sec. The superconducting magnet has produced 64 kOe; it is hoped to increase the field later to 80 kOe.

The copper nuclear stage is presently being readied for the first demagnetization. Even if this is successful many problems, involving thermal isolation, thermal contact, and thermometry must be satisfactorily solved before the cryostat is ready as a research tool.

4.5. Ultrasonic physics (Luukkala, Hattunen).

The coherent breakdown and fusion of ultrasonic phonons have been studied both experimentally and theoretically in anharmonic solids at low temperatures. This has led to several analogies with coherent nonlinear optical interactions.

Two apparatuses, based on the properties of ultrasound, have been constructed. One is for studying the surface anisotropy of Young's modulus in metals and the other for measuring the strength of paper. An extensive research program has been concluded with the former apparatus and the latter has been succesfully tested in paper mills under operational conditions; a patent application is pending.

4.6. Theoretical research (Stenholm, Vuorio).

Two investigations have been undertaken in collaboration with the Mössbauer research group. In the first of these isomer shifts in Eu compounds have been studied. The results show that a phenomenological description of electron density changes at the nucleus,

caused by different types of bonding, suffices to account for the observed effects. In the second study we have investigated whether relaxation phenomena could explain some of the observed features in Mössbauer spectra when magnetic ordering takes place in the lattice.

A third study involves the gas laser. It has been attempted, in the case of single mode operation at high intensities, to bring out similarities between a semiclassical and a quantum mechanical description of a gas laser.

4.7. Technical projects (Sarlin)

Many technical projects are pursued, partly in collaboration with Finnish industry. These include construction and testing of superconducting magnets with associated electronic equipment, development of Mössbauer drive systems with calibration units, and the design and construction of complete dilution cryostats for other universities as a part of joint research projects.

5. VISITS AND COLLABORATION WITH OTHER LABORATORIES

The following persons have participated, during 1969, in our research projects:

Dr. J.A. Good (University of Oxford). Nuclear demagnetization cryostat (5 weeks).

Dr. G.M. Kalvius (Argonne National Laboratory, Argonne, Ill.). Mössbauer effect research (3 months).

Mr. E.R. Seidel (Technische Hochschule, München). Mössbauer effect research (3 months).

Prof. W. Zimmermann, Jr. (University of Minnesota). ^{3}He cryostat (2 1/2 months).

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

Dr. Yu. Anufriyev (Institute for Physical Problems, USSR Academy of Sciences, Moscow).

Dr. M. Borghini (CERN, Geneva).
Mr. H.E. Flotow (Argonne National Laboratory, Argonne, Ill.).
Prof. A.J. Freeman (Northwestern University, Evanston, Ill.),
Dr. R. Giffard (University of Oxford).
Academician P.L. Kapitza (Institute for Physical Problems, USSR Academy of Sciences, Moscow).
Prof. N. Kurti (University of Oxford).

Prof. O.V. Lounasmaa was working as a visiting scientist at the Argonne National Laboratory, Argonne, Ill., on Jan. 13-15, 1969 and at the University of California, La Jolla (Prof. J.C.Wheatley's laboratory) on Jan. 16 - Feb. 18, 1969. He also gave 8 lectures on "New methods for cooling to the millidegree and sub-millidegree region" at the Technische Hochschule, München, on June 1-12, 1969, and a seminar on "The Pomeranchuk method of cooling" at the University of Prague on June 13, 1969.

The laboratory personnel made a group visit in May, 1969, to the solid state physics laboratories at the Royal Institute of Technology in Stockholm (Prof. H.U. Åström) and at the University of Uppsala (Prof. O. Beckman). A group of physicists from Prof. Beckman's laboratory made a return visit to Otaniemi in October, 1969.

Some of our Mössbauer effect research has been done in collaboration with the Solid State Science Division of the Argonne National Laboratory (Dr. G.M. Kalvius) or with Prof. R.L. Mössbauer's laboratory at the Technische Hochschule, München (Dr. F. Wagner and Mr. E.R. Seidel).

Collaboration has been started with the Research Institute for Theoretical Physics at the University of Helsinki (Prof. V. Ambegaokar and Docent E. Byckling).

Prof. O.V. Lounasmaa has been elected a Member of the Finnish Academy of Sciences and a Corresponding Member of the Low Temperature Commission of the International Union of Pure and Applied Physics. He has also been appointed a Member of the Board for the Low Temperature Physics Division of the European Physical Society.

6. PARTICIPATION IN SUMMER SHOOLS AND CONFERENCES

Nordic Summer School on Solid State Physics, Copenhagen, June 26 - July 5, 1969: T.A. Alvesalo, P.M. Berglund, S.T. Islander, T.O. Niinikoski, V.K. Typpi.

Fifth Finnish Summer School in Physics, Liperi, July 23 - Aug. 1, 1969: T.A. Alvesalo, T.E. Katila, S.Stenholm (general secretary), V.K. Typpi, M.J. Vuorio.

The Annual Meeting of the Finnish Physical Society, Feb. 10, 1969: T.E. Katila, invited paper on "Mössbauer measurements in a dilution refrigerator" (in Finnish).

The Inaugural Conference of the European Physical Society, Florence, Apr. 8-12, 1969: O.V. Lounasmaa, as an official representative of the Finnish Physical Society.

Nordic Conference on Refrigeration, Malmö, Sep. 17-19, 1969: R.G. Gylling, paper on "The principle of the dilution refrigerator" (in Swedish).

78th Meeting of the Acoustical Society of America, San Diego Nov. 4-7, 1969: M. Luukkala.

7. PUBLICATIONS DURING 1969

T. Alvesalo, P. Berglund, S. Islander, G.R. Pickett, and W. Zimmermann, Jr., "Specific heat of liquid $^3He/^4He$ mixtures near the junction of the lambda and phase separation curves". Physical Review Letters 22, 1291 (1969).

H.K. Collan, M. Krusius, and G.R. Pickett, "Suppression of the nuclear heat capacity in bismuth metal by very slow spin-lattice relaxation and a new value for the electronic specific heat". Physical Review Letters 23, 11 (1969).

P. Reivari, "Dependence of nuclear polarized ^{57}Fe Mössbauer spectra on the magnitude and sign of the hyperfine field". Physical Review Letters 25, 167 (1969).

A.C. Anderson, B. Holmström, M. Krusius, and G.R. Pickett, "Calorimetric investigation of the hyperfine interactions in metallic Nd, Sm, and Dy". Physical Review 183, 546 (1969).

H.K. Collan, "A simple method for growing single crystals for magnetic cooling experiments". Cryogenics 9, 215 (1969).

M. Luukkala, "On the instability of phonon breakdown". Annales Academiae Scientiarum Fennicae A VI, No. 306 (1969).

G.M. Kalvius, T.E. Katila, and O.V. Lounasmaa, "Mössbauer experiments with a ^{3}He/^{4}He dilution refrigerator". Mössbauer Effect Methodology (Plenum Press; I.J. Gruverman, editor) Vol. 5 (1969).

O.V. Lounasmaa, "New methods for cooling to the millidegree and sub-millidegree region". Scientific American 221, No. 6 (1969).

R.G. Gylling, "The principle of the dilution refrigerator" (in Swedish). Arkhimedes No. 2 (1969).

T.E. Katila and S. Stenholm, "Cold facts about Mössbauer measurements" (in Finnish). Arkhimedes No. 2 (1969).

G.M. Kalvius, G.K. Shenoy, G.J. Ehnholm, T.E. Katila, O.V. Lounasmaa, and P. Reivari, "Quadrupole moment of the 21.7 keV state of ^{151}Eu from Mössbauer measurements". Physical Review (in press).

B. Holmström, A.C. Anderson, and M. Krusius, "Calorimetric investigation of the hyperfine interactions in praseodymium and thulium metals". Physical Review (in press).

D.O. Riska and S. Stenholm, "The effects of detuning on the quantum theory of an inhomogenously broadened laser". Journal of Physics (in press).

S. Stenholm, "The semiclassical theory of the gas laser". Progress in Quantum Electronics (in press).

H.K. Collan, M. Krusius, and G.R. Pickett, "The specific heat of antimony and bismuth between 0.03 and 0.8 K". Physical Review (in press).

S. Stenholm, "The principles of statistical physics" (in Swedish). Reflecta (in press).

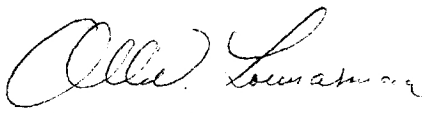
S. Stenholm, "On Hermitian operators". Annales Academiae Scientiarum Fennicae (in press).

A.O. Kajaste and T.E. Katila, "Error signal analyzer for Mössbauer drivers". Journal of Scientific Instruments (in press).

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". Physical Review (in press).

G.J. Ehnholm, T.E. Katila, O.V. Lounasmaa, P. Reivari, G.K. Shenoy, and G.M. Kalvius, "Mössbauer study of hyperfine interactions in divalent europium compounds at very low temperatures". Journal of Low Temperature Physics (in press).

Otaniemi, Dec. 31, 1969



Olli V. Lounasmaa