Low Temperature and Ultrasonics

Laboratories

ANNUAL REPORT 1971

Low Temperature and Ultrasonics Laboratories
Department of Technical Physics
Helsinki University of Technology
Otaniemi, Finland

A N N U A L R E P O R T 1 9 7 1

1. GENERAL INFORMATION

Basic and applied research is mainly conducted in the field of solid state physics; in the low temperature laboratory at the millikelvin and submillikelvin regions of temperature. The low temperature laboratory has been in operation since 1965, and the ultrasonics laboratory since 1969. The laboratories are located in the building of the Department of Technical Physics on the campus of the Helsinki University of Technology, in Otaniemi, 9 km west of the center of Helsinki.

2. PERSONNEL

O.V. Lounasmaa (Research Professor of the Finnish Academy, Director of the Low Temperature Laboratory);

M.V. Luukkala (Associate Professor, Director of the Ultrasonics Laboratory);

E.D. Adams (Visiting Professor, University of Florida, 6 months);

W.J. Huiskamp (Visiting Professor, University of Leiden, 6 months);

N.E. Phillips (Visiting Professor, University of California, Berkeley, 7 months);

J.I. Surakka (Acting Associate Professor);

T.E. Katila (Senior Research Fellow, Docent);

S.T. Stenhom (Docent);

Yu.D. Anufriyev (Ph.D., Visiting Research Fellow, Institute for Physical Problems, Moscow, 5 months);

S.R. Atalla (Ph.D., Visiting Research Fellow, University of Moscow, 1 month);

M. Heath (D.Phil., Visiting Research Fellow, University of Nottingham, 6 months);

P.J. King (D.Phil., Visiting Research Fellow, University of Nottingham, 4 months);

R. Kuentzler (Ph.D., Visiting Research Fellow, University of Strasbourg, 1 month);

R.J. Potton (Ph.D., Visiting Research Fellow, University of Sussex, 8 months);

Barbara Sawicka (Ph.D., Visiting Research Fellow, Institute of Nuclear Physics, Krakow, 3 months);

J.A. Sawicki (Ph.D., Visiting Research Fellow, Jagiellonian University, Krakow, 8 months);

G.K. Shenoy (Ph.D., Technische Hochschule München, 2 months);

Marja Holmström (Lic.Phil., Laboratory Administrator);

Ulla Lähteenmäki (Lic.Phil., Laboratory Administrator);

M.I. Aalto, T.A. Alvesalo, O.C. Avenel, P.M. Berglund, H.K. Collan, G.J. Ehnholm, R.G. Gylling, D.F. Gumprecht, M.A. Hattunen, M.T. Hirvonen, S.T. Islander, M.F. Krusius, L.C. Moberg, T.O. Niinikoski, O.F. Sarlin, V.K. Typpi, P. Wennerström, A. Vetleseter, M. Vuorio (Graduate Students);

A.I. Ahonen, P. Buch Lund, Mona Grönstrand, M.A. Heikkilä, P.J. Karp, S.J. Karttunen, P.T. Meriläinen, K.O. Nores, M.A. Paalanen, R.R. Salomaa, M.J. Valo, Maija Veuro (Undergraduate Students);

Sirkku Jäämies (Laboratory Secretary);

S.I. Kaivola, A. Leinvuo, P.R. Piekkola, N.I. Vehviläinen (Senior Technicians);

E.J. Ahola, T. Heiskanen, M.O. Huhtala, J.M. Kuopio, S. Mannila, E. Mattsson, E. Metsämäki, K.A. Salminen, Hilkka Vainikainen (Technicians).

Three of the graduate students, Moberg (University of Stockholm), Wennerström (University of Uppsala), and Vetleseter (University of Oslo), will spend the Academic year 1971-72 in the laboratory on scholarships from the Nordic Cultural Foundation; Avenel (C.E.N., Saclay) obtained a scholarship through the Franco-Finnish cultural exchange program, and Gumprecht (Free University of Berlin) through Deutsche Forschungsgemeinschaft.

3. ACADEMIC DEGREES

The laboratory personnel has obtained the following Academic Degrees during 1971:

Diploma Engineer: M.T. Hirvonen, R.R. Salomaa.

D.Tech. dissertations: H.K. Collan, G.J. Ehnholm, R.G. Gylling, M.F. Krusius.

4. RESEARCH PROJECTS

4.1. Mössbauer experiments (Katila, Sawicka, Sawicki, Shenoy, Hirvonen, Typpi, Moberg, Gumprecht)

Mössbauer experiments have been conducted in the temperature region from 30 mK to 10 K using a $^3He/^4He$ dilution refrigerator. Gd^{3+} compounds have been studied to determine the nuclear electric quadrupole moment and the magnetic dipole moment of the isotope ^{155}Gd. In addition, information has been gained about the magnetic transition temperatures of these compounds, about their hyperfine interactions, and in some cases about the electronic spin relaxation.

Measurements have been made of the electronic spin relaxation in Fe^{3+} compounds, especially those with S = 1/2. A single crystal of $K_3Fe(CN)_6$ has been studied as well as polycrystalline material. Some other cubic ferricyanides have also been investigated. A method has been introduced to measure long nuclear spin-lattice relaxation times with the aid of the Mössbauer effect. Relaxation times of the order of 8 hours were obtained in polycrystalline $KAu(CN)_2$ below 100 mK by observing the time dependence of the electric hyperfine alignment.

Several technical improvements have been made in the experimental facilities. A 35 kgauss superconducting solenoid has been constructed. Two large programs for analyzing Mössbauer spectra have been transferred to the UNIVAC-computer. The Faraday shield of the experimental room has been completed.

4.2. ^{3}He cryostat (Katila, Islander, Veuro)

The specific heats of two thulium salts, $TmCl_3 \cdot 6H_2O$ and $TmBr_3 \cdot 6H_2O$ have been measured in the temperature range 0.35-6 K. Both salts have a singlet ground state with the first excited state, also a singlet, at about 2 K. Thus the temperature range available in this cryostat has been most suitable for studying the Schottky-type specific heat of the nearly ideal two-level system (the next states lie several tens of Kelvins higher).

Due to the relative simplicity of the crystal field effects in these salts it should be possible to determine the exchange interaction contribution to the specific heats. No sign of magnetic ordering was observed, although the effect of the exchange interactions could be clearly seen as a 15 % reduction of the ordinary Schottky peak.

The specific heat of isotopically pure samarium metal will be measured in the near future.

4.3. Experiments on Pomeranchuk refrigeration (Lounasmaa, Anufriyev, Potton, Aalto, Alvesalo, Wennerström, Buch Lund, Nores, Valo)

A program of investigating the properties of liquid and solid ^{3}He, as a function of temperature, pressure, and magnetic field, has been initiated. Adiabatic compression of a liquid/solid mixture of ^{3}He (Pomeranchuk's method) is used in the final cooling stage.

In the first experiments, adiabatic demagnetization of a chrome-alum salt was employed for precooling to 40 mK; after compression a final temperature of 6 mK was reached. In order to achieve a lower starting temperature for Pomeranchuk cooling a dilution refrigerator has been built and is currently being installed. It is expected that a final temperature in the neighborhood of 2 mK will be reached.

In these experiments temperatures are measured by the pulsed nuclear magnetic resonance method employing ^{195}Pt. This thermometer has been tested between 1 K and 6 mK. The accuracy is within $\pm$ 1 % and the signal-to-noise ratio is satisfactory for calibration against the ^{3}He vapor pressure. It is expected that the thermometer can be made self-calibrating through measuring the spin-lattice relaxation time τ_1, since the Korringa coefficient $\tau_1 T$ for platinum is constant down to 100 mK.

In order to measure directly the pressure in the Pomeranchuk chamber a capacitive pressure sensing device has been constructed and its performance has been tested experimentally at low temperatures.

4.4. Experiments on nuclear refrigeration (Lounasmaa, Phillips, Heath, Collan, Gylling, Aalto, Avenel, Berglund, Vetleseter, Paalanen, Nores)

During 1971 the cryostat has been adapted for measurements of the Kapitza thermal boundary resistance between ^{3}He and a metallic specimen. The aim, backed by some recent theories, is to find alloys for which the Kapitza resistance is not only considerably less than is usually observed with metals but in addition has a different temperature dependence. The discovery of such systems would have a considerable application to the refrigeration of ^{3}He below 2 mK using nuclear demagnetization.

For this purpose a ^{3}He gas handling system and a new experimental chamber have been built. ^{3}He is precooled by a dilution refrigerator and further cooled by demagnetization of CMN. For temperature measurements a SQUID system is used; this measures the nuclear susceptibility of a metal welded to the specimen. The calibration is performed at the very lowest temperatures against a nuclear orientation (^{54}Mn in Ni) thermometer which has good sensitivity between 5 and 30 mK.

The apparatus was ready for the first test experiments by the end of the year and the Kapitza resistance between ^{3}He and copper was measured down to 10 mK. A T^{-3}-dependence between 10 and 150 mK was found, as predicted by the acoustic mismatch theory. However, the absolute value of the boundary resistance was about three times higher than expected from earlier measurements performed elsewhere, but this may be due to the weak electron-phonon coupling in our thin foils.

Further experiments on nuclear refrigeration have been planned. A new superconducting magnet, capable of producing 80 kgauss at 4.2 K and 100 kgauss at 2 K, will be built. Improvements will be made in the superconducting thermal switch between the nuclear and precooling stages. Thermal contact to liquid ^{3}He in the mixing chamber of the dilution refrigerator will be improved by new techniques. A nuclear stage of novel design will be constructed.

4.5. Experiments on polarized targets (Niinikoski)

A horizontal dilution refrigerator of large cooling power, built in Otaniemi, has been put into operation at CERN (Geneva) and the feasibility of a frozen spin polarized proton target has been studied. In such a target the dynamic polarization of protons is separated in time and space from the use of the target in a scattering experiment. The principle is based on the very long relaxation time of protons at low temperatures. For most polarizable materials the temperatures obtainable with dilution refrigerators are sufficiently low.

The relaxation time τ_1 of protons has been measured in two polarizable materials; 1,8-octanediol doped with 15 % Cr^V-glycol complexes, and 95:5 butanol:water doped with 0.59 % porphyrexide. In octanediol, which is solid at room temperature, the longest measured relaxation time was about one month at 54 mK and 15 kOe. The temperature and field dependence of τ_1 was determined in both materials. From these measurements it was concluded that a frozen spin target could be used even at 10 kOe without more than 5 % decrease in the average polarization during a two days' experimental run.

4.6. Ultrasonic waves and their interactions (Luukkala, Surakka, Atalla, King, Hattunen, Heikkilä, Meriläinen)

The nonlinear interactions of ultrasonic volume and surface waves have been studied in various piezoelectric and nonlinear crystals. When two counter directed ultrasonic waves are passing through each other in $LiNbO_3$, a parametric type of nonlinear interaction takes place producing a third signal, the envelope of which is a cross-convolution of the envelopes of the two original signals. This parametric interaction of surface waves is currently being employed to produce real time correlation, convolution, time compression, time stretching, and time inversion. The time-bandwidth product of these simple devices exceeds that of many medium sized computers. In these experiments, 100 MHz surface waves on $LiNbO_3$ have been used. The autoconvolution of coded pulses will also be studied with the intention of producing pulse compression.

The so-called difference-frequency parametric interaction is also under investigation. The subharmonic spectrum of a driven non-linear ultrasonic resonator, such as a quartz disk, is being studied both at room temperature and below. The threshold and some other properties of a non-linear ultrasonic subharmonic oscillator resemble those of a laser. Many properties of non-linear optics can be reproduced with non-linear ultrasonics. The ultrasonic propagation in an isotropic layer supported by a substrate is being investigated by an ultrasonic reflectivity method. A so-called "leaky-wave", propagation mode with a complex wave vector has been found.

Several related technical projects, including nondestructive testing by plate waves are in progress. These include the successful excitation of plates with ultrasound without any mechanical contact or coupling liquid. In cooperation with the local Electron Physics Laboratory, photolithography techniques have been developed. Interdigital surface wave transducers operating up to 200 MHz can now be fabricated using the vacuum evaporation and chemical etching method.

4.7. Applied research (Katila, Aalto, Ahonen, Nores)

An ultrasensitive magnetic gradiometer has been constructed using a superconducting quantum interference device (SQUID). The sensitivity of the system is about 10^{-9} gauss/cm. After the compensation for disturbing fields is improved, the gradiometer will be used for investigating the magnetic activity associated with the human heartbeat. This research has been undertaken in collaboration with Dr. P. Siltanen of Helsinki University's Cardiology Department.

Work on cryoelectronics is rapidly expanding. A thermometer based on the measurement of Nyquist noise has been constructed. The linear relationship between temperature and noise, predicted by theory, has been obtained between 8 and 300 K. The accuracy, which is better than 1 % at room temperature, gradually decreases to 10 % at 8 K. Further work is in progress to extend the range to helium temperatures.

In conjunction with the noise thermometer project, a noise study of the field effect transistors (FET) has been conducted. It was found that at liquid helium temperatures germanium FETs gave an unsurpassed performance at all frequencies whereas the insulated gate FETs were satisfactory only at high frequencies. The employment of silicon junction FETs is feasible only above approximately 70 K where their gain is high. This results in a significant reduction in the total noise compared to room temperature operation. Further experiments are under way to use cooled FETs in nuclear magnetic resonance preamplifiers and noise thermometer amplifiers.

4.8. Theoretical studies (Stenholm, Hirvonen, Salomaa, Vuorio)

Studies are pursued on the further development of the semiclassical theory of multimode laser operation and of the collision theory for a high-intensity gas laser (in collaboration with Helsinki University's Research Institute for Theoretical Physics). In addition, M. Vuorio (at present at the University of Nottingham) is working on the Kapitza thermal boundary resistance between liquid ^{3}He and solids. Both magnetic spin-spin coupling and phonon transmission are being considered. This work is of practical importance for measurements of the properties of ^{3}He at ultralow temperatures, as is planned for the nuclear refrigeration cryostat.

5. VISITS AND COLLABORATION WITH OTHER LABORATORIES

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

Prof. L.J. Challis (University of Nottingham);
Prof. N. Kurti, F.R.S. (University of Oxford);
Dr. L-O. Anderson (Varian AG, Zürich);
Dr. K.N. Zinovyeva (Institute for Physical Problems, Moscow);
Dr. J. Larsson (Stanford University, California);
Dr. J. Kötzler (Technische Hochschule, Darmstadt);
Dr. A.J. Leggett (University of Sussex);
Dr. L. Solie (Norwegian Institute of Technology/ Stanford University, California);
Dr. R.W. Hill (University of Oxford);
Dr. M. Bruun (Technical University of Denmark);
Dr. K.F. Knott (University of Salford);
Dr. E. Hirschkoff (University of California, La Jolla);
Dr. G.R. Pickett (University of Lancaster).

Prof. O.V. Lounasmaa was working as a visiting scientist at the Technion (Israel Institute of Technology, Haifa) from Feb. 20 to March 22, 1971, giving 8 lectures on "Experimental Techniques at Ultralow Temperatures". He has given the following seminars:"Nuclear Refrigeration to the Submillikelvin Range" on May 3, 1971, at the Bell Telephone Laboratory, on May 4, 1971, at the Ohio State University, on May 10, 1971, at the University of Utah, on May 11, 1971, at the Argonne National Laboratory, on May 12, 1971, at the University of Minnesota, and on May 13, 1971, at the University of Illinois (Urbana); "The Superconducting Quantum Interference Device: Theory and Experiments" on November 15, 1971, at Kernforschungsanlage Jülich, on November 16, 1971, at the University of Aachen, on November 18, 1971, at Kernforschungsanlage Karlsruhe, and on November 19, 1971, at Technische Hochschule München.

T.O. Niinikoski was working for the year 1971 in the Nuclear Physics Division at CERN, Geneva, in collaboration with Dr. M. Borghini's group.

S.T. Islander was working at the University of Minnesota from Apr. 1 to June 30, 1971, in the research group of prof. W. Zimmermann, Jr.

Assoc.prof. M.V. Luukkala visited the Technische Hochschule, München, on August 18, 1971 and gave a seminar on "Nonlinearity Parameters in Surface Wave Convoluters and Correlations".

G.J. Ehnholm and M.F. Krusius visited research laboratories working in the fields of low temperature physics and nuclear magnetic resonance, in Grenoble on December 5-12, 1971, and in Paris (Saclay-Orsay) on December 12-19, 1971; they also visited the Kamerlingh Onnes Laboratory in Leiden on December 19-21, 1971; Ehnholm gave 2 seminars on "Nuclear Spin-Lattice Relaxation of the Zeeman and Spin-Spin Systems in Copper between 1 and 17 mK", at C.E.N., Saclay and C.N.R.S., Grenoble, and Krusius gave a seminar on "Nuclear Quadrupole Heat Capacities of the Group V Semimetals" at C.N.R.S., Grenoble.

6. PARTICIPATION IN SUMMER SCHOOLS AND CONFERENCES

Nordic Summer Schoold on Magnetic Properties of Matter, Vålådalen, Sweden, on June 7-19, 1971: O.V. Lounasmaa gave 2 lectures on "The Theory and Use of the SQUID Magnetometer" on June 19, 1971.

European Physical Society: Summer School in Low Temperature Physics, Grenoble, on June 28 - July 10, 1971: participants K.O. Nores, M.A. Paalanen, V.K. Typpi, and Maija Veuro; O.V. Lounasmaa gave 2 lectures, on "Pomeranchuk Effect" and "Thermometry at Ultralow Temperatures" on July 5-6, 1971.

Topics in the Physics of Condensed Matter, Kiljava on July 28 - August 7, 1971: participants T.A. Alvesalo, Barbara Sawicka, J.A. Sawicki, V.K. Typpi, M.J. Valo, and Maija Veuro.

7th International Congress on Acoustics, Budapest, on August 18-24, 1971: M.V. Luukkala, paper on "Acoustic Correlation and Convolution Using Nonlinear Interactions of Surface Waves in $LiNbO_3$".

1971 European Microwave Conference, Stockholm, on August 23-28, 1971: M.V. Luukkala.

Esfahan Symposium on Fundamental and Applied Laser Physics, Iran, on August 29 - September 5, 1971: S. Stenholm.

International Symposium on Nonlinear Optics, Titisee (DDR), on September 6-10, 1971: S. Stenholm.

First European Conference on Physics of Condensed Matter, Firenze, on September 14-17, 1971: O.V. Lounasmaa; G.J. Ehnholm, paper on "Nuclear Spin-Lattice Relaxation Time of Copper between 1 and 10 mK"; S.T. Islander, paper on "Specific Heats of Liquid $^3He/^4He$ Mixtures near the Junction of the Lambda and the Phase Separation Curves"; T.E. Katila, paper on "Magnetic Ordering of $Tm_2(SO_4)_3 \cdot 8H_2O$"; M.F. Krusius, paper on "Nuclear Quadrupole Interaction in Tellurium Doped Bismuth".

International Conference on Mössbauer Spectroscopy, Dresden, on September 20-25, 1971: M.T. Hirvonen, paper on "Relaxation Effects in Mössbauer Spectra of $K_3Fe(CN)_6$ at Very Low Temperatures"

The Annual Meeting of Deutsche Physikalische Gesellschaft, Essen, on September 27-29, 1971: O.V. Lounasmaa was an invited speaker on "New Methods for Approaching the Absolute Zero"; a demonstration on "The Use of the SQUID".

IEEE Ultrasonics Symposium, Miami Beach, on December 6-8, 1971: M.V. Luukkala, paper on "Nonlinearity Parameters in Surface Wave Convoluters and Correlations".

7. PUBLICATIONS DURING 1971

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