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Peter Wyder and his friends in the Villa Vesta 1952-1970
Scientific and other reminiscences

J.L. Olsen

Laboratorium für Festkörperphysik ETH CH-8O93 Zürich Switzerland

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Abstract

Work at the low temperature laboratory of the Swiss Federal Institute of Technology in Zürich during the period 1952-1970 is described. This covers the following: current carrying capacity of superconducting wires in magnetic fields; the difference of moduli of rigidity and of volumes in the normal and superconducting states; pulsed high magnetic fields and magnetoresistance; low temperature engineering projects on the hardness of solidified gas mixtures; heat transfer between cryogenic liquid and gas; superconducting switching elements and current rectifiers; thermal expansion of metals at low temperatures; magnetoresistance and its size effects; size effect in the thermal and electrical resistance in normal metals and superconductors; surface superconductivity; pressure effect in superconductors of the first and second kind; isotope effect; magnetostriction; Hall effect and scattering anisotropy.

1. Introduction

The first laboratory for research at liquid helium temperatures in Switzerland was installed in 1952 at the Federal Institute of Technology (the ETH) in the cellar of an old house the "Villa Vesta", close to the Physics Institute. An account of the early decisions made to make this possible is given in Ref. [1]. The members of the governing committee of this new Helium Laboratory were the professors G. Busch, K. Clusius, H. Staub, and P. Grassmann, Chairman of the Institut fur Kalorische Apparate und Kältetechnik, ETH, who also became Director of the new Helium Laboratory.

It was very fortunate that a singularly bright, friendly and amusing group of students congregated in the Villa Vesta to make their doctorate theses in this new research field. At the time when the laboratory was opened, financial support was scarce. The resulting experiments therefore all required both a good deal of experimental skill and an inventiveness at times close to eccentricity

The Intention of this account is to give a description of the people and experiments around Peter Wyder before and after his period as a graduate student.

2. Early years in Villa Vesta

Professor P. Grassmann had been closely connected with very early fundamental work on superconductivity, and was co-author of the first book on this subject [2]. He also possessed extensive cryogenic engineering experience. On opening the Helium laboratory at the ETH in 1952 he planned to concentrate a considerable portion of its work on making possible the technical use of these fields.

The financial credit for the Collins helium liquefier had been approved in January 1952, and the liquefier space and a workshop were completed by members of the Grassmann Institute in time to accept delivery of the liquefier in early August. The author, a low temperature physicist from Oxford, came as a research assistant with the task of guiding work at the new laboratory. The apparatus was installed in time for the first helium to be liquefied on 27 August 1952. This turned out to be about five weeks later than the first liquefaction of hydrogen achieved in the liquefier built by K. Clusius, the Professor of physical chemistry at the University of Zurich who was himself an eminent low temperature expert and remained a supporter of our Laboratory.

The first graduate student to join the Villa Vesta laboratory was Leo Rinderer who came early in 1953. He began with an investigation of the possibilities of using various superconducting alloys for making magnetic field solenoids. The first experiments in this field were investigations of the critical currents of wires of alloys of lead and bismuth. Such alloys had long been known to have surprisingly high critical fields.

The measurements were carried out in pulsed magnetic fields either parallel or perpendicular to the wire axis. The results showed a remarkable difference between those two field directions [3]. This was not easily understood at the time, and Rinderer studied this phenomenon more closely later.

He also investigated the critical behaviour of pure materials in wire form in transverse and longitudinal fields. The results, which are described in Rinderer's thesis [4], gave a very clear picture of the behaviour to be expected in the rather simple case of pure metals without alloying. The observations gave a very useful background to later applications in industry more complex materials.

During this early period, considerable effort was made to arrange cooperation with industry, and for many years such collaboration existed between the ETH and the Maschinenfabrik Oerlikon (MFO).

3. Start of basic superconductivity research

Although Grassman was very interested in the possibilities of using superconductivity technically, new theoretical approaches to explain superconductivity led us to our first non-applied experiment already in 1953. The latest theory was Fröhlich's [5] proposed in 1950. This was based upon a phonon interaction between the conduction electrons. One prediction of this was the existence of an isotope effect in the transition temperature of superconductors. This had already been observed in mercury during the printing of his theory for publication. The discovery of the effect was regarded as a proof of the theory's correctness.

During a lecture in Zurich in 1952, Fröhlich suggested that his theory might also imply a difference between the velocities of sound in the normal and the superconducting states.

Shortly before the opening of the Helium laboratory W. Pauli had already suggested the desirability of looking for such a difference between the phases. Due to the very small differences between the normal and superconducting volumes it seemed probable that the change would be very small. In spite of this Hans Bömmel from the University of Zürich and Olsen at the Villa Vesta decided to collaborate in making acoustic experiments on tin and lead at ultrasonic frequencies of 1-2 MHz. The Zürich experiment should have allowed detection of a change of one part in $2x10^{-4}$, but no change in velocity was observed. On the other hand an apparent change in acoustic absorption during magnetic flux changes was detected. A brief report by Bömmel and Olsen on these results appeared in Ref. [6].

This work could not be continued in Zurich because of the departure of Bömmel to the Bell Telephone Laboratories in Murray Hill. There he later confirmed a difference of the ultrasonic absorptions in the normal and the superconducting state. The experiments were carried out in the frequency range of 9-27 MHz [7].

Since the ultrasonic work had to be discontinued in Zürich it was decided later to search for a related effect: a difference between the elastic constants of the two phases. This continuation as well as later work on the volume difference between the phases are direct results of Pauli's early interest in the Fröhlich theory.

4. Laboratory expansion 1954-1956

At first, only the cellar of the Villa Vesta had been available for the Helium laboratory. Fortunately, other groups occupying the upper floors of the building felt disturbed by the compressor noise from the liquefaction and in 1954 the ground floor was made available to the laboratory. There one room was given to the Institut fur Kalorische Apparate und Kältetechnik. Two further rooms were made available to Professor Busch's section of the Physikalisches Institut. This allowed a group under the leadership of Jean Müller, helped by E. Bucher and F. Heiniger to start work on low temperature physics, with advice from the original Helium laboratory group. A year later the remaining floors were given over to the laboratory so that all the Villa could be used for low temperatures. The collaboration between the two groups remained close and friendly.

5. The influence of engineers

Grassmann's interest in the technical use of several aspects of very low temperature engineering led to the start of new fields of research in the enlarged laboratory.

The first of these was an effort to determine the hardness of various mixtures of gases which might solidify in the expansion cylinders of helium liquefiers set up in many new low temperature laboratories at that time. It was suspected that such gas crystals were responsible for the high wear observed in these cylinders. A doctoral project by a mechanical engineer Christian Trepp involved the investigation of the hardness of a range of different mixtures of N_2 and O_2 with Ar and Kr as control impurities. It turned out that the techniques used for studying the hardness of metallic alloys could also be used successfully at low temperatures. The hardness of the crystals studied was, however, found to he too low to have caused the cylinder wear observed [8].

A second thesis project was undertaken by Traugott Frederking to investigate the transfer of heat from hot wires immersed in liquid nitrogen and helium. The work on helium included some very early photographic observations of bubble formation below λ point, i.e. in superfluid He II. The influence of the thermomechanical pressure was clearly observed. A range of interesting results were collected [9].

It soon became very clear that the presence of mechanical engineers amongst a group of physicists could provide inspiration and help for the later careers of both groups.

Two electrical engineers came in 1958 and 1964. They were Fritz von Ballmoos and Rene Fasel, who wrote theses on “A study of superconducting switching elements" [10], and "Investigations on current dependent superconducting current control elements and their use in current rectification" [11].

6. Pulsed high magnetic fields

Experiments on lead bismuth alloys had required the generation of magnetic fields up to 0.5 T. Even magnets for such moderate fields were not available in our laboratory. These fields had to be generated by the pulsed magnetic field technique. The heating by such pulses in liquid helium cooled coils was therefore calculated [12]. It became clear that it would be perfectly possible to generate magnetic fields up to 10 T in small coils. This was experimentally verified using coils with an inner diameter of 4 mm. The energy required was provided by a condenser bank. With this field in such small coils only ca 75 cm^3 of liquid helium were evaporated per field discharge. A more detailed technical account of this problem was given by Piero Cotti in his diploma project report [13].

7. Magnetoresistance

As a first use of pulsed magnetic field facilities the change in electrical resistance of copper was studied by Rinderer. First experiments gave data on the magnetoresistance: $\Delta\rho/\rho$ at 4.2 K in longitudinal and transverse magnetic fields up to 13 T [14]. The difference in the values of the magnetoresistance for the two directions is striking. For 13 T one finds $\Delta\rho/\rho$ (long) = 1.6 and $\Delta\rho/\rho$ (trans) = 4.2.

Experiments on magnetoresistance in high magnetic fields were continued by the next research student Bruno Lüthi, who joined the Laboratory early in 1956. He made use of the pulsed field technique in small coils with rather short pulse lengths of only 3-6 ms duration.

Results on polycrystalline specimens in longitudinal fields up to 17 T and transverse fields up to 23 T were collected for 11 metals. These included metals with one, two, three free electrons per atom, namely Cu, Ag, Au, Zn, Al, In, Sn, Pb, and the transition metals, Fe, Ni, and Pt. The data could be represented in the Kohler diagram giving the relative change of resistivity $\Delta\rho/\rho$ as a function $f(B/\rho)$ of the ratio of magnetic field B divided by the resistivity ρ. The measurements provided a wide range of new information about the magnetoresistance of different elements [15].

Lüthi influenced the scientific background of his fellow students in the group vitally by founding a seminar for all laboratory members. This was named the Idioten seminar and remained in successful operation over many years. All those making their doctorate in the Villa Vesta during Lüthi's presence there owe him a great deal for his serious and highly intelligent approach to solid state physics.

8. Superconductivity: basic research continued

The planned search for a change in elastic constants at the superconducting transition was made by using an optical method introduced by Jones [16] for amplifying galvanometer deflections. With this device a change of three parts in 10^6 in the shear modulus in tin at 2 K was found. This varied with temperature as $[1-[T/T_c]^{-4}]$ (see Refs. [17, 18]). As pointed out by Pippard during a visit to our laboratory this modulus is in fact of little importance thermodynamically since there is no volume change associated with the shear.

9. Experiments on volume change

Since the shear modulus seemed to be of little theoretical interest for superconductivity, it was decided to carry on further investigations on other mechanical properties of these substances.

With an optical system related to that previously used for the rigidity modulus, Heini Rohrer built a very sensitive apparatus to measure length changes. This was placed in the very solid cellar of the Villa Vesta to ensure a minimum of mechanical disturbance. In spite of this a low frequency oscillation sometimes appeared, but fortunately only when a strong wind shook the trees around the house.

With his apparatus, Rohrer was able to measure the very small length differences between the normal and superconducting phases. This provided data on the associated volume differences in polycrystalline specimens of the following superconductors: In, Sn, Pb, Hg, Tl, AI, Cd, Ta, La, and V as well as of single crystals of In and of Hg. The relative volume changes: $\Delta v/v$ vary from $5\text{x}10^{-7}$ in Pb to $0.8\text{ x}10^{-7}$ in Al [19].

From these measurements the change in critical field under pressure and the volume dependence of both the critical temperature and of the density of states at the Fermi surface, $N(E)$, could be calculated by making use of the Bardeen et al [20] expression for the transition temperature

$$T_c = 1.13\ \Theta_D \exp[(-N(E)V)^{-1}],$$

where Θ_D is the Debye temperature and V is the electron-electron coupling constant, the data could be used to find the volume dependence of V.

It was found that the total volume dependence of $(N(E)V)$ varied little for the non-transition element superconductors studied. The transition metals, on the other hand, showed large differences in this pressure dependence. A summary of this work is given in Ref. [21].

10. Some sidesteps on the way to normal metal studies (notes by Klaus Andres)

"Shortly after I had joined the low temperature laboratory in the Villa Vesta, Walter Kündig from the Scherrer group suggested to me that the hyperfine field in Terbium could be measured by studying the anisotropy of the γ-emission by oriented Tb nuclei. He came to the Villa Vesta group with this suggestion because low temperatures below 0.1 K were necessary for such an experiment. Olsen was immediately in favour and encouraged me to take part in this experiment. As far as I knew this was the first time that an effort was made in Zurich to reach temperatures below 1K. It was also the first major piece of experimental teamwork both for me and for the Villa Vesta. With advice from Olsen, I quickly learnt the technique of adiabatic demagnetization.

We had only a small electromagnet and too little DC current to run it. We therefore laid a 50 m long thick cable to the lecture hall of the Physics Institute to have a proper current supply. We were soon able to reach 50mK. The whole cellar laboratory of the Villa Vesta was full of counter electronics for the γ-ray anisotropy measurements. It was a wonderful sight, and for the first time I had the feeling of being on the forefront of physical research.

Unfortunately the expected effect did not appear clearly, because the available terbium crystal did not form a sufficiently homogeneous single magnetic domain.

The short, but intense, experience with adiabatic cooling became very useful to me years later when searching for low superconducting transition temperatures in transition metal alloys".

11. Thermal expansion in metals

The actual thesis work by Klaus Andres dealt with the thermal expansion of metals between 1.5 and 12 K. Measurements on thermal expansion of metals at such low temperatures were practically non-existent due to the difficulty of achieving sufficient sensitivity. Andres developed an optical technique allowing measurements of short length changes of ca 2 Å in specimens of 10 cm length. Results were collected for AI, Pb, Pt, Mo, Ta, W, Mg, Cd, Re, Ti, La, Ce, Nd, Gd, and Yb. The electron and the phonon contributions to the expansion were clearly determined [22]. Besides, a number of anomalies in the behaviour of transition metals and rare earth metals were found.

The differences between the thermal expansion in the superconducting and normal states were also observed where relevant.

12. Magnetoresistance and its size effects

Lüthi's high field magnetoresistance results contained those for aluminium and indium where the effect saturates for sufficiently large values of the ratio of magnetic field to resistivity. In this region a number of easily understood galvanomorphic magnetic size effects appear. Some work in this field had begun in the helium laboratory in 1957 [23]. This appeared to be a fruitful field for further investigation.

This was taken up by Piero Cotti who had begun his time at the laboratory with a period helping to develop the high field apparatus and the associated measuring techniques [13]. It is amusing to note that the old high field apparatus continued to be used as a pulsed field background at lower and lower fields since there was still no proper iron core magnet in the laboratory. This was partly a space problem and in part for reasons of economy.

Cotti carried out a wide range of galvanomagnetomorphic investigations under various conditions. His thesis [24] included a number of new methods including one for determining the electronic mean free path by a combination of direct current resistance measurements with eddy current decay time measurements.

His work also included a surprising if somewhat eccentric magnetoresistive phenomenon, which he called the "Zigzag" effect [25]. This is a function of the Hall effect and yields the continuous linear increase in magnetoresistance found in AI and In and in a number of other metals with Fermi surface structures expected to give saturation of the magnetoresistance at the highest fields.

Later the Hall effect in indium alloys was studied by Willem van der Mark and Hans Rudolf Ott [26].

13. Helicon oscillations

The above named galvanomagnetic effect, discovered by Bowers et al [27] in Nd, led to considerable excitement with P. Cotti, P. Wyder and a visitor, A. Quattropani. This turned out to be fairly easy to observe in indium and the three reported on such results obtained in the Villa Vesta soon after the original publication [28].

14. The automobile phase (Klaus Andres)

The character of the Villa Vesta research group was always closely related to their communal amusements. In about 1958, when Klaus Andres joined, bringing with him a 1926 Lancia Lambda it became clear that automobiles were of importance. This was followed by Cotti's 1938 BMW cabriolet and Lüthi and Rohrer's joint Riley of somewhat younger vintage. A number of splendid excursions, usually called "scientific summer schools", were undertaken with these cars by members of the laboratory. Rather embarrassingly, the laboratory often turned out to be almost empty when the Institutsvorsteher came for a visit. This then required some explanation from whoever had remained behind.

15. Size effect in the electrical and thermal resistance of normal metals and superconductors

The above range of investigations were carried out by Peter Wyder, the person being celebrated with this volume. Electron mean free path effects for the electrical resistance had been examined for normal indium previously, and it seemed of interest to compare this with the mean free path corresponding to heat transport in normal metals [29]. A second set of investigations dealt with heat transport in superconductors in the normal and in the superconducting states [30]. This was of interest in considering the theoretical work of Bardeen et al. [31].

A further interesting problem came from the study of some thermal resistance anomalies in the intermediate state of superconductors. The existence of both maxima and minima in this condition had been known from experiments in Oxford and Cambridge since 1948, when they were first reported. A number of possible thermal resistance generating processes had been proposed since then, and were possible explanations for the observed effects. Wyder made measurements of these in indium wires of high purity. His results were explained in terms of the existence of a scattering of electrons at the interphase boundary depending on the energy difference between the two phases. The magnitude of the BCS energy gap should then influence the scattering probability at the boundaries. A discussion of this was given by Sträessler and Wyder [32]. A little later Andreev [33] gave a complete explanation for the case where the scattering was caused purely by reflection at the interfaces. This phenomenon is now known as "Andreev scattering".

Other research in Zürich by Wyder included an anisotropic superconducting heat switch, measurements on size effects in the intermediate state thermal maximum, a heat transport zigzag effect in thermal conduction, Lorenz number of lead in a transverse magnetic field and many more.

16. Surface superconductivity

In his first experiments in the laboratory in 1961 Suso Gygax worked on problems connected with the design of superconducting amplifiers. One of these used a thermal chopping system to modulate the input signal. This arrangement gave a sensitivity of 10^{-11} V. During this period he also made measurements of the critical fields of dilute InPb alloys and other related substances [34].

An exciting new development came from a lecture given in December 1963 by de Gennes at the IBM Research Laboratory near Zürich. He explained that he and D. Saint-James had showed how a thin superconducting layer can exist close to the surface of a superconductor in a magnetic field, $\boldsymbol{H_{c3}}$, which is 1.7 times larger than the $\boldsymbol{H_{c2}}$ given by the Ginzburg-Landau theory [35].

Gygax and a visitor, Richard H. Kropschot from the NBS, Boulder, Cryogenic Engineering Laboratory, started immediately with a search for this effect. Shortly afterwards a note entitled "Four critical fields in superconducting indium lead alloys" appeared, creating a fair amount of excitement and some surprise [36]. Gygax and Kropschot continued work on this subject for a while concentrating mainly on indium lead alloys.

Later studies of associated aspects of surface superconductivity and pinning of flux line structures were made by Piero Martinoli [37].

17. Superconductivity: pressure effects, isotope effect

We explained above that the direct volume change measurements at the boundary between the normal and superconducting phases yielded accurate information on the pressure dependences of both the critical magnetic field and the transition temperature In addition, the pressure dependence of the electron density of states at the Fermi surface and of the electron phonon interaction could be deduced. It had, however, become clear that major differences existed between the effects of pressure on transition and on non-transition elements.

Quite long after the cessation of the volume change work some direct measurements on the linearity of the pressure dependence of the transition temperature T_c were begun. The first metal to be studied was aluminium. This work was carried out by a postdoctoral fellow, Moises Levy, from the University of Pennsylvania. Pressures up to $2.1x10^4$ bar could be generated down to T = 0.7 K. An analysis of the results suggested that pressures $\gg 5x10^5$ bar would be required to reduce T_c to 0 K [38].

An investigation of the problem found earlier the difference of pressure effects in transition and non-transition metals was taken up again by Wolf Wejgaard and Claudio Palmy, who confirmed the existence of such an effect for Ir [39] and for Mo, Os, Th and α-U [40].

At the time this problem was being studied, it was discovered by Geballe et al. [41] that there is no isotope effect in the transition element ruthenium. This led to speculation about whether this is a special transition metal effect or else is simply caused by the low transition temperature of Ru. Palmy, therefore, carried out measurements on Cd with its low T_c of 0.55 K to look for an anomaly in its isotope effect. It is well known that the isotope effect is given by $T_c = M^{-\beta}$ with $\beta = 0.5$ for the normal case.

The results for Cd [42], giving $\beta = 0.35$, show some influence of T_c in this simple case of a non-transition metal. To add a comparison with transition metals two such elements were investigated in collaboration with Bucher and Müller in Geneva [43,44]. For Zr and Mo the following values were found:

for Zr, $T_c = 0.90$ K, $\beta = 0.0 \pm 0.05$
for Mo, $T_c = 0.49$ K, $\beta = -0.37 \pm 0.04$

A further kind of pressure effect came from a suggestion made by Bernd Matthias to the author then a guest in La Jolla to search for superconductivity in tellurium. This is a semimetal but becomes metallic under a pressure of $4.5x10^4$ bar. Matthias was convinced that all substances of this kind should become superconducting in the metallic phase. For a bet with La Jolla it was decided to carry out the experiments in the Villa Vesta. There with the excellent technical help of Paul Caminada pressures up to ca $5.6x10^4$ bar were generated between truncated tungsten carbide cones pressing on a Te sample. A superconducting transition was observed using a low frequency mutual inductance method. On reduction of the pressure to about $4.0x10^4$ bar the transition disappeared [45].

The influence of pressure on the Ginzburg-Landau Parameter κ was investigated by Erich Fischer His apparatus allowed the application of pressures of up to $12x10^3$bar on slim cylindrical ellipsoids. Alloys of InTI and InPb were studied. The magnitude of κ depends on both the electronic specific heat constant γ and the resistivity ρ. These in turn depend upon the volume, and κ therefore depends in a somewhat complicated way upon the pressure [46].

18. Magnetostriction

Andres [23] had shown very clearly the good use that could be made of his mechanical and optical device for measuring very small length changes. Gerold Brändli who planned to measure such dimension changes in type II superconductors realized that the capacitor method used by White [47] would be much more convenient and more accurate for the ellipsoidal specimens to be investigated. In Ref [48] the devices designed by him and by Ronald Griessen are described.

In his thesis, Brand1i describes measurements made on a series of alloys of InPb, InTI, TaNb and on pure lead and pure tantalum. Both longitudinal and transverse length changes could be measured. Observations were also done during magnetic cycling of surface supercurrents [49]. Calculations of the following effects are given:
(1) the influence of the Ginzburg-Landau parameter;
(2) magnetostriction due to surface supercurrents in the mixed state and in the state of surface superconductivity;
(3) influence of the form of the specimen on the magnetostriction [50].

Ronald Griessen later changed his field of interest to that of the de Haas-van Alphen effect induced magnetostriction in normal metals.

19. Transfer of Hönggerberg (1970)

The Villa Vesta laboratory was torn down to make room for a new building m summer 1970. The laboratory members then moved to the newly built Physics Department on the Hönggerberg away from the centre of the ETH in Zürich. There a fine new "Laboratorium für Festkörperphysik" awaited them and they could move in during the late summer.

Five members who had begun work in Villa Vesta before the move were able to complete their doctoral theses in the excellent new laboratory. These were W. Wejgaard, W. van der Mark, P. Martinoli, H. R. Ott, and R. Griessen.

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