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Low-temperature physics in Switzerland. A historical review

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Abstract. A rather personal review of various highlights of Swiss low-temperature physics, with some more emphasis on the earlier days. May the contemporaries forgive me!

I. Introduction

It is obviously impossible to define the beginning of low-temperature physics in general and, even more so, if the development of this particular branch of science should be considered for Switzerland alone. One may even ask the legitimate question whether low-temperature physics can be regarded as an autonomous field in physics at all, but it appears to be answered most convincingly by the mere existence of multi-volume proceedings of, up to now, sixteen international conferences held on this subject. It should be mentioned, however, that the first such conference was held only in 1949, indicating that the need for specialization was not so urgent before that time. The starting of this series of conferences is certainly closely related with the fact, that liquid helium became suddenly available to many laboratories (see also at the end of section II) and with the ending of a rather long period of time where this, at that time, precious liquid could be produced only at very few places, among them Leyden, Toronto, Berlin and Breslau.

The present short story is an attempt to review some of the work related with physics and low temperatures (as ill defined as they may be) that was done in Switzerland. Most of the basic information was obtained from the reports on the meetings of the Swiss Physical Society (SPG = Schweizerische Physikalische Gesellschaft), published up to 1928 in 'Les Archives des Sciences Physiques et Naturelles', which appeared in Geneva, Paris, London and New York, and with a tradition dating back to 1795! After 1928, these reports were and still are printed in 'Helvetica Physica Acta'.[1]

With the limited time and space available, this review in no way claims to be complete and the author apologizes in advance for any, certainly unintentional

[1]) At least for historical searches, the abstracts of the SPG-meetings are extremely useful and younger physicists are well advised to use this opportunity if they intend their work to be rediscovered after some length of time.

omission of important work he may not be aware of. It is hoped, however, that the reader may find it amusing to obtain some information on historical facts in relation with physics and low temperatures in Switzerland, which may not be readily available for everybody. For exactly that reason, the earlier achievements are discussed in somewhat more detail than more recent developments.

II. –1950

A very natural entry into 'low temperature physics in Switzerland' is provided by one of the highlights of the early struggles for lower temperature, namely the first liquefaction of air, achieved at almost the same time by M. L. Cailletet in France and R. Pictet in Switzerland in December 1877. The story on and around this important discovery is very well narrated and documented in an article by N. Kurti, written on the occasion of the 100th anniversary of the first liquefaction of air [1]. Like his French colleague, Pictet, the Swiss, was interested in many fields, and a lot of his discoveries found immediate applications for industrial purposes, mostly in firms he directed himself. Although he was not, strictly speaking, a physicist, he seems to have participated regularly and actively at the meetings of the Swiss Physical Society. He was still interested in the liquefaction and subsequent purification of gases 30 to 40 years after his great success, at a time which marks the beginning of the systematic investigations of physical properties of matter at lower temperatures.

An important contribution of 'Swiss physics' in this direction was the attempt of A. Einstein in 1906 to explain the unexpected temperature dependence of the specific heat of solids at low temperatures [2], then most extensively studied experimentally by Nernst and his collaborators in Berlin. Although the model of Einstein provided a deviation from the classical value of Dulong and Petit in the direction that was observed experimentally, the agreement with experiment was still poor. The leading institution in the production of low temperatures at that time was, without any doubt, the laboratory of H. Kamerlingh Onnes at the university of Leyden. Since the experimental facilities in Switzerland were much less well developed in this particular field, a few Swiss physicists started collaborations with Onnes, so to mention P. Weiss of ETH Zürich and A. Perrier, soon to become professor at the University of Lausanne.

At the SPG-meeting of 1910, held in Neuchâtel, P. Weiss reported about measurements of the magnetization of Ni, Co, Fe and Fe_3O_4 down to 15 K, reached by pumping a bath of liquid hydrogen [3]. It is worth mentioning that the magnet providing the necessary magnetic fields and also parts of the apparatus to measure the magnetization of the samples were transferred from Zürich to Leyden, because that technique was especially well mastered by Weiss and his collaborators. At the same meeting, Weiss also gave a short account of magnetization measurements on solid oxygen carried out by Perrier and Onnes at Leyden. As indicated above, R. Pictet was still active in the field and at the SPG-meeting in 1911, he reported on a new method of extracting very pure oxygen, probably for medical applications, out of air, a process which was based on the liquefaction of air [4].

Meanwhile the new measurements of the magnetic susceptibility χ of various substances (O_2, Dy_2O_3, $FeSO_4$) by Perrier and Onnes aroused the interest of P.

Debye, then at the university of Zürich, and he made again at an SPG-meeting, a novel suggestion as to why, as found experimentally, χ does not follow a Curie–Langevin law ($\chi \sim 1/T$) down to low temperatures [5]. Probably for the first time he invoked the then called 'hypothesis of quanta' in the calculation of χ and suggested that in certain cases

$$\chi = (C/T)e^{-\varepsilon/kT},$$

a first, although nebulous recognition of what was much later fully worked out by Van Vleck.

Only one year later, Debye presented yet another application of the quantum hypothesis, namely the calculation of the specific heat of solids at low temperatures [6]. At the 1912 SPG spring-meeting in Berne he gave the preliminary results of his ideas and demonstrated, why

$$c_p \sim T^3.$$

He explicitely argued that this result was a direct analogy to the famous T^4-law of Stefan and Boltzmann. At the same meeting he also discussed some consequences of Nernst's law and showed that it demanded a zero temperature gradient of the magnetization for a magnetic system at $T = 0$ K, in analogy to the disappearance of the thermal expansion coefficient at zero temperature. Again at the same meeting, A. Perrier presented the latest results of his susceptibility measurements down to 14 K [7]. Unfortunately it was not possible to track down more details on a cited maximum of χ found on not explicitely mentioned substances with decreasing temperature [8]. It seems quite possible, however, that Perrier and Onnes observed the antiferromagnetic transition of $FeSO_4$ at about $T = 21$ K. In Ref. 9, Perrier and Onnes give an extended account on the temperature dependence of the initial susceptibility of nickel at very low temperatures. The goal of this work was to check the theoretical prediction of Weiss' molecular-field model, that $\chi(T = 0) = 0$, i.e. complete saturation of the magnetization at zero temperature. It appears that Perrier was Onnes' specialist for magnetic measurements at low temperatures. He obviously built, for that time, a very large and powerful liquid hydrogen cryostat especially for these experiments [9]. Probably because of sensitivity problems, quite large samples of the material under investigation had to be cooled, and this also explains why none of these measurements were done using liquid helium. The amount of liquid helium available in Leyden during these years was by far too small for cooling such a cryostat. In 1913, Perrier returned to Lausanne and continued his work in the field of magnetism but, as much as his publications reveal, without any more experiments below 0°C. We also should like to mention that in the same year (1913), Einstein and Stern published a paper dealing with the remaining motion at $T = 0$, the well known zero point energy [10], a result of their cooperation in Zürich.

After this quite productive and successful era of Swiss attempts to study thermal properties of solids at low temperatures, the interests shifted to other problems until 1918, P. Weiss and A. Piccard of ETH Zürich made an important discovery for later developments in low-temperature physics, although their experiments were done above room temperature [11]. They found that a magnetic material warmed up when exposed to high magnetic fields and they called this phenomenon 'the magnetocaloric effect'. They also checked the reversibility of the effect thereby discarding any explanations based on the known hysteretic losses of ferromagnets. It was then A. Perrier who, at the 1921 SPG-meeting in Schaffhausen, discussed the possibilities of how to use this effect for refrigeration [12]. It may well be that, on this occasion, he was the first to discuss this idea, which a few years later was borne out more completely by Debye [13] and Giauque [14].

Debye wrote an article entitled 'Einige Bemerkungen zur Magnetisierung bei tiefer Temperatur', which was received by the 'Annalen der Physik' on October 30, 1926. Because Debye was, at that time, professor of physics at ETH Zürich, his paper may be regarded as another, extraordinary highlight of Swiss contributions to the progress in low-temperature physics and therefore it deserves some further comments. In his article, Debye first demonstrates that the Langevin formula for the magnetization of a system with n particles each with a moment μ in a magnetic field H

$$m = n\mu(\coth(\mu H/kT - (\mu H/kT)^{-1})$$

although in very good agreement with experimental results of Kamerlingh Onnes on gadolinium sulphate around 1 K, must be fundamentally wrong, because it is incompatible with Nernst's law. He also mentions that other formulae for m, based on quantum theory avoid this difficulty. However, in the second part of his paper, Debye uses the Langevin formula as a still useful tool to discuss the consequences of adiabatic processes on magnetic systems like gadolinium sulphate, by increasing or decreasing an external magnetic field. He concludes that adiabatic demagnetization of such a system should result in an appreciable temperature decrease. Because of the limitations of the Langevin formula he hesitates, however, to claim as to how close to the absolute zero such a process would still be efficient. Nevertheless he encourages experimentalists to check his proposal.

Not very much activity in experimental low-temperature physics can be reported, however, for the period between 1920 and 1930. It was again theoretical work, this time by A. Schidlof at the University of Geneva, treating the properties of fluids at very low temperature, which should be mentioned. Starting in 1924, Schidlof examined the application of the newly developed statistics of Bose on the general properties of gases and he especially studied the degeneracy conditions. In 1926, he applied his theory to the properties of liquid helium [15]. From its critical parameters he predicted a minimum of the molar volume V_m between 2 and 3 K and concluded that this explained the density maximum observed by Onnes. He also stated, that without any artificial increase of V_m, liquid helium could not be cooled below about 2 K. Only two years later, Schidlof published some results concerning the magnetism at very low temperatures by invoking the spin degeneracy of electrons [16]. Experimentally the lowest temperatures attained in Switzerland at that time were obtained by the use of liquid air or liquid oxygen. In Neuchâtel, Jaquerod and Mügeli measured low temperature elastic moduli of Pd and some alloys by using liquid oxygen [17]. At the University of Zürich, M. Schein used liquid air cooled tubes to focus atomic beams [18]. Also at the University of Zürich, R. Bär was among the first ever to study the temperature dependence of Raman spectra by cooling samples of solid ethyl ether to liquid air temperatures [19].

Between June 28 and July 1, 1933, ETH Zürich organized a lecture series on modern physics and the two main topics were low-temperature physics and nuclear physics [20]. The lecturers for our special object were W. Meissner of

Berlin, W. H. Keesom of Leyden and F. Simon of Breslau. Meissner talked about the work of his group on superconductivity and on some attempts to isolate a new isotope of hydrogen by means of low temperature techniques. He discussed the studies to characterize the state of superconductivity and described the experimental set-up which finally led to the discovery of the Meissner-Ochsenfeld effect in the fall of 1933. Keesom reviewed the thermal properties of liquid helium and F. Simon discussed the problems of calorimetry at low temperatures with regard to Nernst's law. Simon also presented his views of how to liquify helium. These lectures, especially the last one, apparently had no great impact on the projects in Swiss experimental physics, at least as low temperatures were concerned. Temperatures of liquid air were, for some time still, the lower limit. In 1934, Pankow and Scherrer studied the temperature dependence of the intensity of x-ray interference patterns on Li [21] in order to determine the Debye temperature with a new method and to compare it with values obtained as usually from specific-heat measurements [22]. At the same time, E. Lips at ETH Zürich measured the temperature dependence of the magnetization of solid NO [23]. The experiments were thought to provide a test for Van Vleck's then recent theory on paramagnetism. Liquid air was also used for the investigation of low temperature thermal properties of the newly discovered ferroelectrics (e.g. KH_2PO_4) by G. Busch between 1933 and 1938 at ETH Zürich [24]. In 1935, susceptibility measurements to liquid hydrogen temperatures carried out by Busch in Berlin, indicated a second phase transition of KH_2PO_4 [25] (see also Ref. 28). Also in 1935, Hablützel (ETH) measured the thermal expansion of Seignette's salt down to $-110°C$ [26]. Further experiments which should be mentioned are the measurements of sound velocities in liquid O_2 by Bär and Liepmann at the University of Zürich [27]. Just before the second world war, Busch and Ganz had the opportunity to measure dielectric constants of some ferroelectrics down to liquid hydrogen temperatures at the Mond laboratory in Cambridge [28], which confirmed the conjectured phase transitions (see above).

It was not until 1945, that temperatures below that of liquid air were available in Switzerland, when Gibert and Rossel, with the aid of Ganz, built a hydrogen liquefier [29]. Liquid hydrogen was subsequently used to measure neutron cross sections on solid N_2 and KH_2PO_4 [30].

As already mentioned in the introduction, a new era, also for Switzerland, began after the end of World War II, essentially with an article which appeared in the Review of Scientific Instruments and its author was S. C. Collins [31]. In his work, Collins described a versatile helium liquefier which in the end led to the worldwide, rather easy access to liquid helium because the concept was picked up by an industrial firm (A. D. Little Company) who made these machines commercially available. The first advertisements appeared in 1949 and it was G. Busch at ETH Zürich who initiated the first contacts with the American firm and investigated the possibilities to buy and install a helium liquefier in Zürich.

III. 1950–

Before the acquisition of this helium liquefier, several problems had to be solved. At first, it was by no means clear, who would deliver the necessary amount of helium gas and negotiations on a guarantee that the gas could be purchased in the United States finally succeeded. As always in cases where investments for new research installations involving relatively large amounts of money are planned, it was also then essential that the project be supported by various potential users with their prospective plans for future activities, and a committee of several professors of ETH Zürich (G. Busch, P. Scherrer, P. Grassmann) and of the University of Zürich (K. Clusius, H. Staub) was formed to take care of this important task. It also had to be decided, where the new liquefier should be installed and who should be responsible for its operation and maintenance. The location was chosen to be close to where most of the users were to be expected (the institute of physics of ETH) and it was decided to install the liquefier in a cellar of an old villa (Villa Vesta) next to the physics building. It was also decided that P. Grassmann should be responsible for the operative part and for the provision of technical know-how for experimental problems in this new range of temperature. For that purpose a position for an experienced low-temperature physicist was created.

While in Zürich, the planning for the installation of low temperature facilities was fervently pushed forward, other Swiss physicists still went abroad for experiments at temperatures below that of liquid air. As an example we mention J. P. Jan of the University of Lausanne, who did some Hall-effect measurements on Ni and Fe down to 14 K in Leyden [32]. Even there and then, liquid helium was not available so easily for everybody.

At the same time, K. Clusius felt that the existing installations for hydrogenation of metals at the University of Zürich could easily and without much money be incorporated in new facilities for the liquefaction of hydrogen.

To cut a long story short, both projects were granted in late 1951, the first liquefaction of hydrogen took place on July 18, 1952 and the first drop of helium

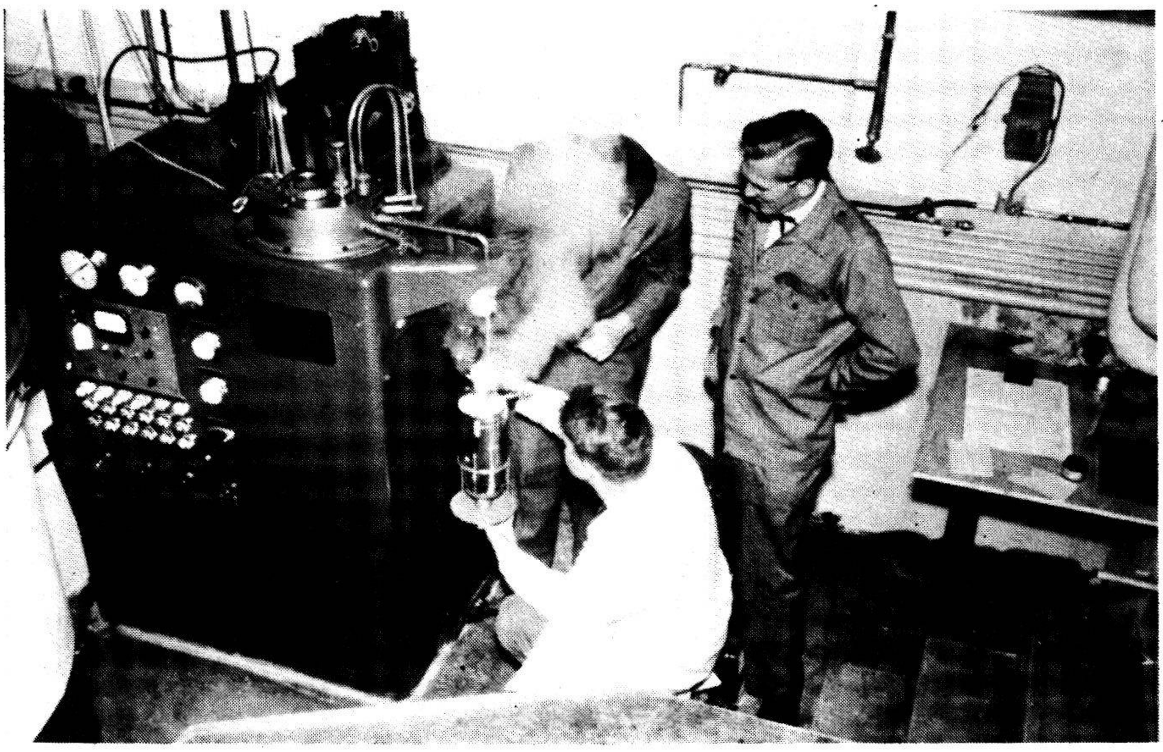

Figure 1
Three midmen delivering the baby "Swiss liquid helium".

was produced on August 27, 1952. Actively present on this latter, historically important occasion for low-temperature physics in Switzerland, was a fresh D. phil. from Oxford, J. L. Olsen. Thus he, whose 60th birthday is celebrated with this issue of Helvetica Physica Acta, took an active part in what we still may call 'low temperature physics' in Switzerland right from the beginning. Probably the first paper containing experimental data in the temperature range of liquid helium that was produced in Switzerland was that of Bömmel and Olsen, on the velocity of sound in superconducting tin and lead [33], a cooperation between ETH and the University of Zürich. As a first 'application' of the newly available refrigerant, we mention the production of high, pulsed magnetic fields with copper coils immersed in liquid helium [34]. While the very first activities using liquid helium were concentrated in Grassmann's institute for process engineering and cryogenics, very soon also members of the institute of physics took advantage of the newly accessible range of temperatures, among them K. A. Müller, who measured the paramagnetic resonance of Mn^{2+} in ZnS down to 4.2 K [35].

It should be noted, that the 'helium laboratory' of ETH Zürich served as a source for the spreading of low temperature techniques in Switzerland after only a few years of existence. It was L. Rinderer, the first Ph.D. student of the low temperature group, who, after leaving ETH, installed a nitrogen- and a helium liquefier at the University of Lausanne in 1957, mainly for research on superconductivity. Ch. Trepp, one of the first Swiss engineers specializing in low-temperature techniques, joined Sulzer and was involved in developing large gas liquefiers. As a result, some of the largest existing helium liquefiers were built by Sulzer during the last 20 years. In 1964, J. Müller, a collaborator of Busch and involved in studies on the superconductivity of transition metals and compounds, accepted a nomination as professor of physics in Geneva and he immediately initiated low temperature research, using liquid helium, there too. At about the same time, MFO (Maschinenfabrik Oerlikon) started a low-temperature lab in connection with their magnet-production program and a lot of know-how was acquired in collaboration and with the help of the ETH helium laboratory.

Meanwhile the urge for still lower temperatures persisted and it was J. L. Olsen who first pushed the limit to below 1 K in Switzerland by means of adiabatic demagnetization of paramagnetic salts, to measure the pressure dependence of critical superconducting parameters of Al [36]. With essentially the same techniques as for helium-4, temperatures below 1 K can also be obtained by using helium-3. This very rare isotope, however, was not available in Switzerland before nuclear-weapon industry released it as a by-product in sufficient quantities which made it commercially available at reasonable prices. The first Swiss helium-3 cryostat was again installed at the helium lab of ETH and mostly used for experiments to study the effect of pressure on superconductors with low critical temperatures [37].

The availability of ^3He in sufficient quantities in the early sixties gave way to the application of an ingenious process, invented by H. London [38], to reach temperatures below 0.1 K, the continuous dilution of ^3He in ^4He. The efficiency and the technical improvements of such machines were mainly developed in the United States and in France and they replaced the conventional cooling devices based on adiabatic demagnetizations of salts. In the early seventies, cryostats based on this principle were installed both at ETH Zürich and at the University of Geneva. It should also be mentioned, that another new technique for reaching very low temperatures (~1 mK), by hyperfine-enhanced nuclear cooling, theoretically predicted by Al'tshuler [39], was experimentally first realized by two ex-helium-laboratorians, namely K. Andres and E. Bucher, then both with Bell Laboratories [40]. Such a device was then later also installed at ETH Zürich, reaching temperatures of the order of 1 mK.

To conclude, we note that in the last 15 years, the use of low temperatures in the range of liquid helium has grown immensely as well in physics as also in other, related sciences all over Switzerland. Most laboratories, university or industry, involved in solid-state research use liquid helium regularly. The fact that at ETH Zürich, e.g., the institutes for physical chemistry, molecular biology, geophysics and electrical engineering, among others, use liquid helium indicates the diversification of the applications of low-temperature technology. Liquid helium is also a must for nuclear- and particle physics both at SIN in Villigen and CERN in Geneva, as well as for neutron experiments at EIR Würenlingen.

Obviously, low-temperature physics has quite a glorious history in Switzerland. Let's keep up the standard!

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