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The origins of solid state physics in Italy: 1945 – 1960

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Abstract: The Italian physicists who devoted themselves to solid state physics in the early post-war period could not rely on a solid cultural heritage such as that left by Fermi and Rossi in nuclear, subnuclear, and cosmic ray physics. Solid state physics in Italy resulted from a polycentric process stimulated by local situations and contacts with foreign research groups, European or American. Many factors hindered this process. Among them was a cultural, political, and industrial context unconcerned with a discipline whose theoretical foundations and possible technical applications appeared uncertain, the disciplinary formation of new physicists until based on a curriculum established in 1936, and the scarce financial support. The topics studied in those years covered many fields: magnetic properties of materials, color centers in alkali halides, semiconductors, nuclear and electron magnetic resonance, imperfections in solids, neutron diffraction, and superconductivity. Theoretically, the main contributions were to semiconductor bands' theory and alkali halides' structure and defects.

Keywords: Solid State Physics, Physics of Matter, Italy

1. Introduction

The definition of a discipline requires the identification of its field of investigation, the awareness of the scholars who practice it to operate in this field, and their organization into a community. These elements are not necessarily all present, and their interweaving is historically determined. The appearance of a theory encompassing fundamental phenomena favors identifying a new field of research. On this basis, solid state physics (SSP) began to develop in the thirties of the past century when the band's theory of crystalline solids gave the theoretical foundation for the distinction between insulators, conductors, and semiconductors. The publication of the book *The Modern Theory of Solids* by Frederick Seitz (1940) significantly contributed to identifying this new branch of physics. The invention of the point-contact transistor by John Bardeen and Walter Brattain (1947) can be considered the closing act of a half-century-long research on point-contact rectifiers and opened the way – theoretically traced by William Shockley – to the building of the p-n junction transistor (1952). In 1960, Theodore Harold Maiman built the first (pulsed) solid-state laser.

In the following pages, we shall describe the birth of solid state physics in Italy, considering reports and recollections of physicists (Giuliani, 1988), their interviews (Bonizzoni, 2002), and preliminary historical reconstructions (Giuliani, 2002; Marazzini & Rossi, 2005; Rossi, 2007).

2. Meanwhile, in Italy

On the eve of World War II, the community of Italian academic physicists still had a nineteenth-century structure. The small number of physicists (127 in 1940), the size of the research groups (three to four units), the scarce funding (both absolute and compared to other countries), and the strong centralism made the Italian physical community very weak. This weakness also reflected the fragility of scientific research in Italy. The renewal of the research staff was slow and difficult because of the scarcity of new positions and the limited availability of graduates (Galdabini & Giuliani, 1988; Giuliani 1996, pp. 1-6). At the end of the war, the international context for physical research appeared profoundly changed: the defeat of Nazism and Fascism and the war devastation in Europe favored the shift of economic hegemony across the Atlantic. The US effort to produce the nuclear fission bomb has shown the efficiency of research based on the concentration of human and material resources and the planned interweaving between basic research, applied research and technology.

The use of nuclear fission bombs on Hiroshima and Nagasaki has once again dramatically brought to the fore the role of science and its applications; the division of the world into two blocs and the onset of the Cold War revived the arms race. The growing governments' interest in the military and civil applications of scientific discoveries implied an increasing economic effort of their countries. Scientists not only saw their number increase considerably but also became aware of the acceleration of the integration of science into society, of the growing influence of their organizations on specific decision-making processes, and of their increasing responsibility, also ethical.

Italy's problems were complex and they were made more difficult by the devastations of war, the overall weakness of scientific structures, the widespread inability to grasp emerging innovations, and the connection between education, research, technology, and development.

After the liberation of the country from the nazi-fascists, Italian physicists endeavored to reconstruct the buildings, recover laboratory instruments - sometimes hidden to prevent theft from the German troops in retreat - and construct new equipment using also the remnants of war abandoned by Allied troops[1]. The training of students who entered the course in Physics in the immediate post-war period was based on an out-of-date study plan established in 1937, which would remain in force until 1961 (Giuliani, 1996, pp. 21-23).

3. Solid state physics in Italy

Solid state Physics developed in a polycentric way throughout the country, within or beside the older research traditions of the physics of atoms and molecules. Indeed, we should better speak of the development in Italy of what will be called later the Physics of Matter. In the beginning, this polycentric development was characterized by scarce connections within the Italian groups. More important were the collaborations with foreign teams, European or American (US) (Giuliani, 1988). In the following, we shall draw a synthetic picture of the groups' geographical locations and their research.

3.1. The 'Galileo Ferraris' Institute, Turin

The 'Galileo Ferraris' was born as a project of the *Società Idroelettrica Piemonte*, which, in March 1929, allocated ten million lire. It risked being abandoned due to the significant economic crisis of that period. The joint intervention of the municipality of Turin and the State re-launched the project, and the Institute opened in 1935. University researchers (School of Electrical Engineering of the Polytechnic) and researchers hired on a fixed-term contract worked at the Institute. The annual budget was two million Lire, assured by law by the government. For the dimension of financial support, the joint contribution of public and private institutions, and the number of technicians per researcher, "Galileo Ferraris" represented an

[1] Adriano Gozzini vividly recalled: "Before leaving Pisa, the German mined and blew up a wing of the Institute with its tower. Anna Ciccone, the only person present at the Institute at that particular time, refused to abandon it and retired to the other wing of the building. After the mines had been exploded, the German withdrew taking with them the best optical instruments. When Anna Ciccone saw that, she precipitated on the soldiers in a fury, as an enraged tigress would defend her offspring, offering the soldiers the alternative of killing her on the spot or renouncing their removal. Fortunately, they chose the latter alternative, so that the best of these (including a Michelson échelon and a diffraction grating autographed by Rowland, now conserved at Certosa di Calci) had been saved. Whoever knew Anna Ciccone, can imagine the scene" (Gozzini, 1988, p. 67).

exception in the Italian research landscape. In Solid State Physics, the contribution of 'Galileo Ferraris', in the period under review, was mainly in the field of magnetic properties of materials. Initially, the section was directed by Carlo Chiodi and Valentino Zerbini. In the post-war period, research on magnetic properties was carried out by Giorgio Montalenti (1915-1990) and coworkers.

3.2. Physics of matter in Pavia

The group of Pavia grew around the figure of Luigi Giulotto (1911-1986)[2]. Piero Caldirola (1914-1984) and Giulotto opened a happy and lasting season of collaboration. The two physicists (Giulotto experimentalist and Caldirola theorist) also wrote some papers. However, the nature of their collaboration, based on mutual esteem, was essentially characterized by discussions on 'what to do?'. Caldirola suggested to Giulotto to study the composite spectrum of the H_α line of the hydrogen atom[3] and, later, to deal with the new technique of nuclear magnetic resonance.

The challenging experiment on the H_α line started in 1942 and was completed only in 1947 due to the war events. The experiment reasonably confirmed the discrepancy between Dirac's theory and experimental data. Shortly after, Lamb and Retherford showed that the level $2p_{1/2}$ is about 1058 MHz lower in energy than the level $2s_{1/2}$ by directly observing the transition between the two levels, using a microwave beam of the appropriate wavelength. The theoretical description was then given by quantum electrodynamics. This case may be emblematic of Italy's technological underdevelopment and the gap between some fields of physics and their counterparts at the international level. Giulotto approached the problem with traditional spectroscopic methods, and Lamb refined it, inspired by a fully quantum view of the problem. The development of microwave technology in the United States during the war and for military purposes made this experimentally possible.

In 1946, Giulotto set up a nuclear resonance apparatus by assembling old instruments found at the Institute, except the transmitter built by a radio engineer, then a voluntary assistant. Since Giulotto did not have an oscilloscope, he heard the first resonance signal through a headset, which was a sharp sound superimposed on the background noise due to the electrical network [4]. This experiment began a happy season that allowed Giulotto and his coworkers to rank among the world's leading groups in this field until the mid-1950s (Bonera & Rigamonti, 1988, p. 62).

At the beginning of the fifties, Caldirola put Giulotto in touch with Fausto Fumi (1924-2009), a theorist of Solid State. The project was to create a theoretical - experimental Solid State Physics research group. At the end of 1959, in addition to Fumi, Franco Bassani (theorist, 1929-2008) and Gianfranco Chiarotti (experimentalist, 1928-2017), also Paolo Camagni (experimentalist, 1931-2000), Mario Tosi (theorist, 1932-2015) and Vittorio Celli (theorist, 1936) were in Pavia. The project's failure - due to harsh personal conflicts between the two leaders – caused the scattering of the group. Bassani, Tosi, and Celli moved to the USA, Camagni to the Ispra Center, and Chiarotti (1962) to Messina. According to Chiarotti, the loss of this opportunity was compensated by the country's dissemination of Solid State Physics (Bonizzoni, 2002, p. 155).

The topics studied in Pavia were color centers in alkali-halides and, starting in 1960, semiconductors.[5] The research on color centers has proved less far-sighted than that on semiconductors. Indeed, although cleverly calibrated, Frederick Seitz's emphasis on this area of research (1946) needed to be more balanced. In 1960, color centers research focused on Chiarotti's idea of studying the X-ray production of color

[2] Giulotto's archive is available online at fisica.unipv.it

[3] fisica.unipv.it

[4] fisica.unipv.it

[5] Semiconductors were studied also in Rome (Istituto di Elettroacustica) by Daniele Sette (1918-2013) and his coworkers.

centers in KCl at low temperatures, including liquid helium. There were two challenging issues: mastering the cryogenic techniques starting from scratch and the need to operate in the UV region below 200 nm, i.e., in a vacuum. Chiarotti's goal revealed disproportionate in consideration of the available budget and the consequent necessity of self-training. These difficulties were overcome in about five years. After that, the research continued until the mid-seventies, with results of some interest (Falomo Bernarduzzi, Bevilacqua & Giuliani, 2020, pp. 435-436).

Chiarotti used a modulation technique for studying surface electron states in semiconductors. The energy of the surface states was modulated by applying an alternating electric field, and the light reflected from the surface was measured at the same frequency as the applied electric field, thus obtaining a high sensitivity. Andrea Frova (1937) systematically applied this new technique that became a standard procedure in studying surface electronic states, along with the modulation of the light wavelength (modulation spectroscopy) (Rossi, 2007, pp. 12-13).

On the theoretical side, Bassani and Celli significantly contributed to the band theory in semiconductors. A significant number of papers by Bassani, as those on the pseudo-potential developed with Celli and the collaboration with many foreign researchers, brought his name to the international community's attention. Indeed, Bassani's work trained the first generation of Italian theoretical physicists in solid state (Rossi, 2007, pp. 16-20).

3.3. *Between Milan and Parma*

The development of the Pavia group was accompanied by the formation of a theoretical-experimental research group in Milan: the leader was Roberto Fieschi (1928). At the end of the fifties, Fieschi, with Caldirola's support, ventured into the organization of an experimental research group on color centers in alkali-halides investigated with a multiple experimental approach: optical absorption, luminescence, thermoluminescence, and ionic conductivity. In 1964, Fieschi went to Parma with some of his coworkers. Fieschi, together with Andrea Levialdi (1911-1969), proposed the foundation of a CNR laboratory on the structure of matter. Its main characteristic - advocated by Levialdi - would have been the interweaving of cultural and professional skills of chemists and physicists. The laboratory will be built and, according to Fieschi, its ideal director would have been Levialdi who, unfortunately, succumbed to an incurable disease during a work trip to Cuba (1969).

3.4. *Genoa*

The Genova group developed around Giovanni Boato (1924-2009). Boato took the degree in Chemistry in 1946 (Genoa) and the degree in Physics in 1950 (Rome). In September 1952, Boato moved to Chicago, where he worked with Harold Urey, known in Rome through Amaldi. He returned to Italy in 1954, and, after a short stay in Rome, he moved to Genoa, invited by Ettore Pancini. In Rome, Boato became familiar with the low temperatures techniques and mass spectrometry (Giorgio Careri). In 1957, Boato attended the Varenna School on Solid State Physics organized by Fausto Fumi. "In Varenna, I came into contact for the first time with the wide range of problems of crystalline bodies, and I was lucky enough to meet some European and US top solid-state physicists" (Boato, 1988, p. 198). Back to Genova, Boato decided to open new research lines with his direct collaborators, including Giacinto Scoles and Carlo Rizzuto: transport properties of rare gases in solid state and superconductivity.

3.5. *Pisa*

Adriano Gozzini (1917-1994), alumnus of the *Scuola Normale Superiore*, graduated in Physics in 1940. Recalled to the arms immediately after graduation, he returned to Pisa in 1945. Using US military material, he built a microwave laboratory. Meanwhile, Nello Carrara founded in Florence (1946) what, a year later, became the CNR Microwave Center.

After the retirement of Luigi Puccianti, Carrara was appointed as director of the Pisa institute. The research carried out by Gozzini's group gained international relevance over the years, as witnessed also by the names of some visitors: Alfred Kastler, Charles Hard Townes and Nicolaas Bloembergen. Kastler's interest was stimulated by Gozzini's work on the Faraday effect in paramagnetic substances in the microwaves region (1951), an effect predicted by Kastler himself. These magneto-optical effects were later intensively studied in many French and Russian laboratories. For the Pisa's institute, those were years of rapid and lively growth: Carrara was called to the chair of Fisica Superiore in Florence; Marcello Conversi to the chair of General Physics in Pisa; later, Luigi Radicati to the chair of Theoretical Physics and Giorgio Salvini to that of Fisica Superiore. In1960, Gozzini organized a Summer school on radio frequency spectroscopy in Varenna: "The Proceedings of the School are collected in a volume which has proved to be an extensively used textbook in the sixties, and even today it is still extremely useful" (Gozzini, 1988, p. 72).

3.6. Rome

Giorgio Careri (1922-2008) graduated in Industrial Engineering and Chemistry in Rome in December 1944, immediately after the city was liberated. After graduating, he refused a job offer and graduated in Physics (1946). Edoardo Amaldi asked Careri to build a mass spectrometer. "I had to build something I did not even know the name of". The construction of the spectrometer faced the typical difficulties of the years of reconstruction. The U.S. still considered the mass spectrometer a strategic material (until 1950): therefore, it was not possible to buy any components. Emilio Segre, violating a ban, brought from the U.S. a couple of resistors of $10^{12}\ \Omega$, necessary for the input circuit of the ions detector. Voltage stabilizers were not available. "We had to obtain the needed 200 V with batteries of accumulators abandoned by the U.S Army. Every night, some died, and early in the morning, we had to go hunting for those who had died during the night and replace them". In 1954, after the decision to build a 1.1 GeV synchrotron in Frascati, Amaldi appointed Careri as director of the cryogenic laboratory to merge the acquisition of cryogenic techniques with research in low-temperature Physics. The mass spectrometer was used to study chemical kinetics and geochemistry problems. The cryogenic techniques to study the diffusion coefficients in diluted mixtures of H_2-D_2 and ^3He-^4He, ions motion in liquid helium, and electrically charged vortices in liquid helium.

3.7. Palermo

The development of the physics of matter in Palermo is linked to the names of Ugo Palma (1027-2012) and Beatrice Vittorelli Palma (1930-2008). Ugo Palma graduated in Physics in Palermo in 1947; Beatrice Vittorelli four years later. The director of the Insitute of Physics was then Enrico Medi (1911-1974). His leadership was remembered by the Palma's as follows: "These [six years since the end of the war] had been blank years for the Istituto di Fisica, a delay difficult to overcome. All the worst, those years were perhaps crucial in preparing the future decision of Donato Palumbo and Gaetano Riccobono of leaving Palermo (Palma & Palma, 1988, p. 142)". The idea of acquiring the electronic paramagnetic resonance (ESR) technique came to Donato Palumbo. Only later, the small group became aware that the ESR technique could be widely used for the study of solid properties. The arrival in Palermo of Mariano Santangelo as director of the Institute marked a turning point: "He brought an atmosphere, previously unheard, of encouraging friendship, discussions and hard work. He made room for any activity or project to have a chance to progress. His presence opened a decade of great stability, instrumental to all further developments (Palma & Palma, 1988, pp. 141-142)". In 1957, the Sicilian Region established and financed a Regional Committee for Physical research. The INFN was also involved with positive consequences for Palermo's group: six technicians and several research collaborations. With these funds, the group also bought a helium liquefier (1959), which allowed the acquisition of cryogenic techniques. The research topics developed in Palermo included: interactions between electronic and vibrational transitions in magnetic crystals; collective motions of protons in non-ferroelectric crystals; ion and electronic cascades in light-sensitive crystals; and electronic paramagnetic resonance of free radicals.

3.8. Physics of Matter at Ispra

At the end of 1957, the CNRN (National Committee for Nuclear Research, established in 1952), in agreement with Fumi and Giulotto favored the creation of a small group in Pavia with the prospect of transferring it to the new nuclear Center of Ispra. Paolo Camagni (1931-2000) coordinated the group and moved to Ispra in 1959. Camagni was joined by Adriano Manara and by Alfonso Merlini (1926-2014) who was entrusted with the group's direction. Camagni continued researching the production and the properties of defects in crystalline solids. Merlini's group studied the properties of solids with X-ray techniques. The difficulties associated with installing the new laboratories were accentuated by the decision (1959) to transform the Ispra's Center into a European Community facility. The research programs were revised immediately to adapt to the new institution's goals. The transformation of the Center into a European community structure has progressively reduced the role of the Solid State Physics Laboratory.

3.9. Solid State and neutron diffraction

Given the construction of the Ispra Center, the CNRN, on a proposal from Amaldi, decided to set up a research group to study the properties of solids with neutron diffraction. Initially (1957), Giuseppe Caglioti (1931), recalled by Argonne, Antonio Paoletti (1930-2019) and Francesco Paolo Ricci (1930-2000) were involved in the project. During the construction of the spectrometer and the installation of the reactor at Ispra, the members of the research team were sent to work for about twelve months in U.S. laboratories: Caglioti at Chalk River, Paoletti at Brookhaven and Ricci at MIT. When they returned to Italy, the projects had changed. The CNRN became CNEN, and the Ispra Center became a center of the European Community. The CNEN decided to set up its own research Center in Rome (at Casaccia): Caglioti and Ricci went to Ispra, while Paoletti went to Casaccia, where he developed the first European polarized neutrons spectrometer, which was used to study the magnetization density in metals and ferromagnetic alloys. The two groups became operational in 1960. However, The "Ippolito case", which upset the CNEN in 1963, negatively impacted these groups' activity.

4. Becoming an organized community

After the war, the reference points in Italy were the nuclear and cosmic rays physics, and the cultural heritage of Enrico Fermi and Bruno Rossi. Edoardo Amaldi worked to re-launch cosmic rays and nuclear physics research since the immediate post-war period. In 1951, he succeeded in establishing the National Nuclear Physics Institute (INFN) as a structure of coordination of three pre-existing CNR centers, thus putting the basis for direct funding by the State of Nuclear and Elementary Particle Physics. This goal was reached, step by step, in 1971 with the complete organizational autonomy of the INFN. These choices created an imbalance in the organization and funding of physical research in Italy and between physical research and other experimental disciplines. The physicists, who, for local contingencies or personal choices, were oriented toward what would later be called the Physics of Matter, devoid of solid cultural and organizational references in the pre-war period, were forced to look abroad. The connections between physics of matter researchers were mainly indirect, through the Italian Physical Society (SIF) congresses and, later, through the schools of Varenna. In particular, the School of 1956, organized by Giulotto, that of the following year, organized by Fumi, and that of 1960, organized by Gozzini. The first institutional recognition of the Physics of Matter took place in 1961 with the introduction of the course "Struttura della Materia" (Structure of Matter). The process of institutionalization of the research started in the first sixties. It ended, apparently, in 1994 with the foundation of the INFM (National Institute for the Physics of Matter), financed directly by the government as it happened in 1971 for the INFN. Indeed, in 2003, the government of Mr. Berlusconi, without any wariness about the fate of a young research structure and its impact on a strategic research field, inserted the INFM into the restructured CNR, leaving outside the other two National Institutes (INFN, INAF) (Bonizzoni & Giuliani, 2002, pp. 22-34)[6].

5. Epilogue

The post-war period saw scientists, as well as many Italians, engaged in the process of reconstruction made dramatic by the war's devastation, the overall backwardness of the country, and its scientific structures. The progressive increase in the number of physicists, the raising of their professional profile, and the increasing research funding allowed the Italian community of physicists to enter entirely - in about two decades - within the wider international community.

Nowadays, scientific research depends on the country's productivity and the decision-maker's capacity to create a farsighted vision for future generations. Both these conditions are missing. Indeed, a country in which the education system is not considered the foundation of the future, a country from which young graduates migrate without their output flow being balanced, both quantitatively and qualitatively, a country where the average technological level of the industry is lagging, and the materials and equipment of the research laboratories come, to a considerable extent, from abroad; such a country and its scientific research is set to play an increasingly marginal role in the international context. This was certainly not the hope of the scientists who, after the material and moral devastation of the war, had taken up again with enthusiasm to "question Nature".

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[6] Table 1 on p. 24 shows two errors: the data in column 5 misses a zero, and the data in column 6 must be divided by ten.

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