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MICROWAVE PHYSICS IN PISA IN THE FIFTIES

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In October 1945 I set off on what was then an adventuresome journey from Florence to Pisa to visit Luigi Puccianti, after five years of absence. I found him in his study in the half-destroyed Institute absorbed in a newly published book "Questioni di Fisica" by G. Bernardini and G. Polvani. As I entered the room he raised his eyes from the book, said "ciao Gozzini" and became absorbed again in his reading. After about ten more minutes Bernardini and Carrara entered the study. They too had come to visit their old "maestro" after years of absence. He greeted them with a "ciao Gilberto, ciao Nello" and returned once again to reading the book. After several minutes he got up and left the room leaving us dumbfounded. This was my first encounter, after five years of absence, with my old "maestro".

A few days later I received a letter from him in which he offered me the temporary position of "assistente supplente" in substitution of Prof. Lamberto Allegretti who had not yet returned from his wartime occupation[1].

The Institute's condition after the end of the war was and much the same as that of other Institutes. The building was semidestroyed, the library impoverished, due to subtraction of the books, subscriptions to the journals suspended for years. Instrumentation, already scarse before the war, had been partially removed by the Germans[2].

The teaching staff was composed of the Associate Professors Anna Ciccone, Tullio Derenzini, Cosimo De Donatis and Lamberto Allegretti, whom, as I mentioned above, I had

[1] It was in this manner that I became a member of the Institute of Physics. I had taken my degree with Puccianti in June 1940 and since that date I had not even touched a physics book. Nowadays endowed and promising graduates who have not been fortunate enough to have had some type of scholarship during those particular years favoured by various "ope legis" agreements, after years of post-doctorate studies, voluntary research work and brilliant publications, do not have any possibility of enrollment in the university. Comparing the latter situation with my own personal experience I may infer that the immediate postwar years were not "gli anni difficili" at least from that particular point of view.

[2] Before leaving Pisa the Germans mined and blew up a wing of the Institute with its tower. Anna Ciccone, the only person present in 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 Germans 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 on 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 in the museum of Certosa di Calci) had been saved. Whoever knew Anna Ciccone can imagine the scene.

been called on to substitute, by two elderly technicians, by a doorkeeper-carpenter, Otello Serraglini, and by Teresa employed as a cleaner and forever quarreling with an exacting Miss Ciccone. Besides the Professor, this was the roll of the Institute.

In those years teaching and the supervision of the theses of the numerous students, ex-service men, was the unique activity. During those years, amongst others, Carlo Castagnoli, Gerardo Alzetta, Arrigo Battaglia, Ruggero Renzoni, Giulio Chella, Aulio Stura, Silvio Gibellato, and Cesare Marchetti graduated.

A depot of stores had been left by the American troops in the nearby camp of Tombolo. That material was subsequently marketed in the Arar stores, but at that time was sold clandestinely. For just a few lire it was possible to buy marvelous objects, such as klystrons, magnetrons and sophisticated electronic apparata. Puccianti made a small sum available for purchasing such merchandise and we started using it for the degree theses of the majority of those mentioned above[3].

The periodicals, interrupted during the war years were resumed and from this literature it appeared that microwaves had indeed opened up new and promising fields of investigation (microwave spectroscopy, EPR etc.). In the meantime Alzetta, Battaglia and Stura had obtained their degrees and, while waiting to find suitable jobs, they still attended the Institute. We then decided to form a small research group. This only survived for a few months because Battaglia found a position at the Naval Academy, Stura at the Leghorn high school, and Alzetta in industry.

Puccianti retired at about that period and the direction of the Institute was entrusted to Nello Carrara, father in Italy of ultrashort waves. (Among other things during the war years he had constructed a unique specimen of a prototype radar, in collaboration with Prof. Tiberio.) Carrara, together with Toraldo di Francia, Schafner, Checcacci, Laura Ronchi and others, had been organizing the "Centro Microonde" in Florence, now IROE (Research Institute of Electromagnetic Waves). With his arrival the activity in microwave physics received a notable impulse. In those years he performed in Florence a beautiful piece of research on the angular momentum of em waves. That research, as I shall recount further on, inspired a technique for studying non linear processes in E.P.R. In the meantime I had initiated measurements of the dielectric constant of gases (Nuovo Cimento 1951).

In 1948 appeared a work by Wilson and Hull in Physical Review (Phys. Rev. 74, 711, 1948); they had studied the Faraday effect at a frequency of 9 GHz in numerous substances, without finding a measurable rotation except for the case of some manganese salts. Since the effect is inversely proportional to the square of the wavelength, and it is very small at optical frequencies, I perceived that the Macaluso-Corbino effect was involved, that is to say a resonance of the Faraday rotation that manifests itself in the vicinity of an absorption band. A few years before the electronic paramagnetic resonance had been discovered, and the Mn^{++} salts are paramagnetic. The American authors had performed their experiments with weak magnetic field values for which the absorption due to magnetic resonance at that frequency begins to appear. Therefore it could be predicted that the effect would have been much larger with more intense fields, that it would present a resonance character and would provide an interesting technique for studying paramagnetic resonance.

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[3] For several years that material was practically the only modern instrumentation available, which would allow research in a still unexplored region of the em spectrum. The first piece of original research performed in the Institute in that period was the argument of Gibellato's degree thesis, a theoretical and experimental analysis of the evanescent field and of its reflection by a mirror. This study performed at 9 GHz provided a detailed analysis of the phenomenon of total reflection; was published (Nuovo Cimento 1949-ibidem 1950) and taken up again in the field of optics many years later with the advent of the laser. Gibellato died still a young man just a few years later.

After having overcome the difficulties of providing a sufficiently intense magnetic field and of creating a simple apparatus I published the work in 1951. It was a rather special event because it preceded an analogous much more extensive work of Hogan (1952) on ferrites and permitted the realization of non reciprocal devices of great interest for radar technology. But the more important fallout of this work resides in the fact that it interested Prof. Alfred Kastler of the Paris' Ecole Normale who had predicted it. (C.R. Acad. Sci. 228, 1640, (1949)) He wrote to me and came to Pisa, and we established a friendship and a collaboration which have been of inestimable value to me. Kastler suggested investigating also the transverse effect (the Cotton-Mouton effect) which he had also predicted (C. R. Acad. Sci. 231, 1462, 1950) and which we detected some time later (Nuovo Cimento 1953)[4]

These magnetooptic effects turned out to be an interesting field of research. It was taken up by many French and Russian laboratories. In Italy it was extensively investigated by the EPR group of the University of Parma (D'Ascola and collaborators) who also performed research on monocrystals, discriminating effects due to crystalline anisotropy from those due to EPR. In Pisa became the subject of many theses during the next few years (Pietro Bucci and Mario Iannuzzi).

In those same years Carrara had stipulated in Florence a contract between the "Centro Microonde" and the American Airforce related to various studies on the physics of microwaves. Among the other research work prospected were some studies on the dielectric properties of the atmospheric gases and, in particular, on the spectroscopy of O_2 and of water vapour at millimetric frequencies, problems related to radar. Carrara entrusted these to the Pisa group which in this way gained disposal of equipment not yet available commercially, such as millimetric klystrons, and was able to appoint a technician (Gino Ciampi), who very soon became a precious collaborator. In the context of those research projects various apparata were constructed, the most important of which was an instrument for measuring with a high degree of sensitivity and precision small differences between the frequencies and the quality factor of two resonators, by means of a very simple impulsive technique. The instrument, conceived initially as a spectrometer, was later subjected to a great deal of improvement and adaptation in order to measure small variations of whatsoever a physical quantity that could be associated with a variation in frequency or of the Q value of a resonator. Under the terms of the contract we were able to study the spectroscopy of O_2, of great interest because of the particular nature of that spectrum, and of water vapour, and we were able to obtain a precise measurement of the dielectric properties of the atmospheric gases. We were also able to offer hospitality to some foreign research workers, amongst whom Bruin, husband and wife, of Amsterdam, George Boudouris, (presently Rector of Athens Polytechnic), Demetre Ilias and F. Diamond from Paris. In a mutual exchange program some Pisa research workers were able to take advantage of scholarships for abroad. Polacco and Fornaca spent a period in Paris at the Institut H. Poincaré, Battaglia was a guest at the Zeeman Laboratory in Amsterdam, where with Heiniken they reproduced the previously mentioned spectrometer with which they measured the spectrum of HN_3, and Polacco and Ianuzzi spent a period in England at Oxford.

In the early fifties Nello Carrara was called to the chair of "Fisica Superiore" (Advanced Physics) of Florence University and Marcello Conversi was called to Pisa to the chair of "Fisica Generale" (General Physics - the only chair existing in the Institute at that

[4] In the early fifties Professor René Freymann and Alfred Kastler organized the "Groupment AMPERE" (Atomes et Molecules Par Etudes Radioélectriques) whose activity consisted in the publication of a reference Bulletin and in the organization of a yearly colloquium, the first being held in Paris in 1952. We participated in these meetings and had the opportunity to interact with the leading physicists in the field; Gorter, Townes, Ingram, Bleaney, Abragam, Powles and many others. The membership in the Ampere group was of great importance for the research development in Pisa.

time). In a few years the Institute was reorganized. Administrative offices, an electronics laboratory and a mechanics workshop were created, run by extremely efficient persons[5]. New chairs were obtained and filled, that of "Fisica Teorica" (Theoretical Physics), to which Luigi A. Radicati was called, and that of "Fisica Superiore" (Advanced Physics) to which Giorgio Salvini was called.

Radicati organized theoretical physics research, Conversi and Salvini research on cosmic rays physics. Conversi called two assistant professors from Rome, Giuseppe Martelli and Elio Fabri and Pisa obtained a subsection (and later a section) of I.N.F.N., the National Institute of Nuclear Physics. The Institute saw its importance increase to the extent that the organization of the 1955 International Conference on Elementary Particles was entrusted to it. In those same years it hosted the team of research workers and technicians that constructed the Frascati electron-synchrotron, and later, after the team moved to Rome, it hosted the group that created (on the suggestion by Enrico Fermi) the first large electronic computer in Italy (CEP, the Pisa Electronic Calculator) which was housed for several years in the Institute.

These episodes permitted a rapid reconstruction of the premises that had been destroyed and a notable growth of the technical services. However, the space that previously had been more than sufficient now became critical and all the available room from the basement to the attic was being utilized for experimental research[6].

As far as the microwave activity is concerned, with the return of Alzetta and Battaglia, and the graduation of Erseo Polacco, Giuseppe Fornaca, and Mario Iannuzzi, a permanent group was formed, which was not limited only to myself and an occasional graduating student, and we obtained financial contributions form CNR.

As I mentioned previously, Carrara had performed a beautiful experiment at the Centro Microonde in which he had detected the angular momentum flux associated with the flux of energy carried by a beam of circularly polarized em waves. He directed the incident circularly polarized radiation emitted by a magnetron on a special mirror hung on a torsion wire which reflected the beam thereby inverting the sign of the circular polarization. The mirror was thus subjected to a mechanical torque $2P/\omega$ which was measured by the torsion of the wire[7].

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[5] Amongst others I especially wish to recall Ugo Della Croce (electronics), Armando Pecchi (in charge of the workshop) and the secretaries Miriam Fanucci, Vivetta Della Capanna, Angela Cocchella, Graziella Renzoni).

[6] At one stage some of the rooms were divided horizontally, reducing the height with scaffolding and thereby doubling the available area. At a later stage that problem was solved by renting apartments for some of those laboratories.

[7] A problem which immediately arose was that of the origin of the energy acquired by the pendulum, and it was immediately demonstrated (and besides there was no other possible source of energy) that it came from the radiation, whose frequency is modified when the polarizer is made to rotate about the direction of the beam propagation. A kind of "rotational Doppler effect" occurs, due to the change of sign, rather than of the momentum, of the angular momentum of the light. In the case of reflection or transmission with a change of sign of a circularly polarized beam, the frequency ω of the reflected of transmitted radiation by a polarizer that rotates with a frequency Ω around the direction of the bean is $\omega = \omega_o (1 + \Omega/\omega_o)$ analogous to that of the Doppler effect, where the linear velocities are substituted by the angular velocities of the polarizer and of the light. Alzetta and Polacco verified this immediately bay interposing a rotating half wavelength plate in the trajectory of the polarized monochromatic bean. We communicated this result to Persico, thinking that we had discovered an interesting optical effect of motion, which we had never seen discussed in any book on optics that we had consulted. Persico sent us a reference to a work by Augusto Righi (published in Comptes Rendus

Such a torque is clearly present in all those cases in which the circular polarization of the beam is modified, and in particular when the radiation interacts with a medium that possesses circular dichroism, such as in the case of magnetic resonance. Simple estimates show that theoretically the measurement of the torque associated with the absorption for MR provides a sensitive technique for detecting MR, superior to the radioelectric method in the case of low frequency and high intensity experiments. After various unsuccessful attempts to detect this effect, due to the lack of skill in manipulating thin quartz wires, to the difficulty of eliminating mechanical forces produced by the external field on the magnetic sample, and to the mechanical noise of the environment, Alzetta observed a small effect and the experiment was rapidly realized. The experiment proved to be an important method for investigating non linear effects in EPR absorption. It was later studied accurately by Ennio Arimondo and extended to the detection of paramagnetic dispersion.

In an experiment designed to detect the presence of traces of polar impurities in a non polar liquid, Battaglia and myself saw that a powerful (1 Mw) but brief (1 ms) em impulse emitted by a magnetron was not able to trigger a discharge in a neon tube if this was expose to the pulse in complete darkness[8].

Discussing this result with Conversi, we attributed it to the fact that, in the absence of light and therefore of the photoelectric effect on the electrodes of the neon tube, the probability that there could be a free electron density in the gas sufficient to trigger the discharge in such a brief time interval was practically zero, and we decided to utilize this to make a path detector of ionizing particles. This was constructed (hodoscopic chamber, flash tubes) and was presented at the elementary particle conference (1955) in a communication by Conversi. The hodoscopic chamber has been used extensively in cosmic radiation research and, some years later, the spark chamber was constructed by Japanese physicists using the same principles.

In the second half of the fifties research developed in various direction. In the microwave spectroscopy of gases results were obtained regarding the form and width of spectral lines and on phenomena of saturation, which led (for the first time in molecular spectroscopy) to the detection of two photon transition processes, previously observed in atomic spectroscopy with the technique of optical pumping. Adriano Di Giacomo, who graduated at that time, gave a complete theory of the process in perfect agreement with the experimental results. The latter process became a precious technique in microwave spectroscopy in subsequent years. In the field of the width of spectral lines, besides furnishing a theoretical support to the experimental work, Di Giacomo formed a small theoretical research group which is still in activity. Alzetta and Santucci applied the EPR techniques to the study of various solid state physics phenomena, and with Fornaca we started experimenting using the elegant, simple and powerful optical pumping technique, a field in which it was shown that a magnetic rotatory power is associated with the atomic orientation, an effect which results to be a sensitive non-destructive technique for the detection of the orientation itself, and which has been applied to a number of problems. In the late fifties the group was engaged in organizing two important events which took place in 1960. The first was a

at the end of the last century), in which he reported that effect. It was utilized many years later in a thesis by Roberto Calabrese "Single photon beats" (Nuovo Cimento 1987).

8 In this experiment a magnetron pulse was directed on a cell containing the fluid in question exposed to a light beam in order to see whether a strong signal was emitted by the photomultiplier receiving the light scattered by the liquid in coincidence with the pulse. In the presence of traces of polar impurities the dipoles should have produced a local heating under the action of the field with a consequent local variation of the refractive index of the scattered light. Kastler provided us with extremely pure specimens of cyclohesane. The experiment was performed in the dark and since nothing appeared to happen, I and Battaglia checked the performance of the magnetron by exposing a neon tube to the pulse. This lit up when the room was illuminated but not in the dark.

summer school in Varenna, entrusted to me by G. Polvani, the second the IX Colloque Ampère.

The school was held in July on topics of radiofrequency spectroscopy. It was the second to be held on this subject matter, the first having been organized by Giulotto in 1956. As in the latter case, and thanks to the contribution of physicists such as Kastler, Townes, Cohen-Tannoudji, Brossel, Abragam, Skalinski, Shimoda and many others, the event was, as one might say, extremely exciting (among other things, the possibility of constructing an "Optical Maser" was discussed there anticipating its effective realization by a few months). 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. The IX Colloque Ampère was held in Pisa at the Scuola Normale in September. Many more research physicists participated than in preceding conferences. Since then these conferences have gradually lost the pleasant atmosphere of meetings between friends having a common interest and have evolved into the present-day megaconferences.

In December of that same year 1960 the Science Faculty of Pisa University conferred the degree honoris causa in physics on Alfred Kastler to honour his figure as a scientist and in recognition of his contribution to research developments in Pisa. In the subsequent sixties the group increased in size with the aggregation of the then new generation. Franco Bassani was called to Pisa, and research developed in several new directions including Solid State Physics, Biophysics and Atomic Physics. At the end of the sixties two laboratories of CNR were created, one dedicated to biophysics, the other to atomic and molecular physics.

Recalling those years the difference between the possibilities of present-day research activity and what was possible in the immediate postwar period is enormous. Equally great is the difference between the atmosphere in which research was then performed and that which exist nowadays. The scanty facilities, the precariousness of the positions then available, the lack of continuous reunions and bureaucratic obligations, the freedom of initiative and of research all together rendered the atmosphere, in my opinion, relaxed and pleasant. The philosophy of those years was that expressed by the Sicilian cart-drivers song that the Palma's presented as a preface to their contribution to this encounter: "If Good wants and the mule plods on, we will get to the Bivona fair" (in the meantime let us enjoy ourselves). Fatiguing along, the mule proceeded and something has been done. This would not have been possible without the work of a relatively small number of people, mainly of my friends and colleagues Giuseppe Fornaca and Arrigo Battaglia who are no longer with us and to whose memory I dedicate these pages.

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