Manuel Cardona: Extraordinary Scientist, Teacher and Human Being—A View from Argentina

Francisco de la Cruz

Manuel Cardona has been one of the most successful contemporary physicists. He was an extraordinary scientist enjoying the creation and dissemination of knowledge through collaborative work with colleagues and students.

Manuel published more than thirteen hundred scientific articles and wrote several books that are used by students and professors at different levels of education and research. Many of his former students are today outstanding scientists serving universities as well as the industry in the United States, Germany, Spain, Italy, France, England, Russia, Israel, China, Japan, Cuba, Brazil, Chile, Mexico, Argentina, and other countries. He not only taught physics and trained dozens of scientists: he educated his students and colleagues in questions that touch upon ethics, particularly when applying a society's limited resources to science and education.

Manuel could have been a theoretical as well as an experimental physicist. He chose to lead research in laboratories where many experimental physicists became trained. His broad and deep understanding of physics was shined when interpreting experimental results as well as when he planned future actions. His daily presence discussing results, suggesting experiments and, quite frequently, bringing information on social and political problems, made Manuel's lab not only productive in science but a stimulating meeting point. His interest in the social and political agenda problems became part of the formation of citizens.

Cardona had a privileged intelligence. He was fast suggesting ideas and procedures to understand new phenomena. He enjoyed sharing initiatives with colleagues and particularly with the many students he advised over the course of his life. He was able to mentor students that were simultaneously doing research in a wide range of scientific subjects. Manuel himself wrote papers on an equally wide range of topics. He was a gifted writer and seldomly had to revisit his initial drafts. On the other hand, it was interesting to see how many hand written "suggestions" and "annotations" he made on manuscripts "carefully" elaborated by his students. Usually, Manuel's observations were correct, but it was a pleasure and a challenge to discover, from time to time, that he was not always right.

Manuel Cardona was born on September 7, 1934 in Barcelona, Spain, two years before the beginning of the Spanish Civil War. As many other Spaniards he and his

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family suffered the consequence of war, and he retained the horror of the war in his memory. Manuel attended high school in a prestigious school in Barcelona. In 1955 he graduated with excellent marks as "licenciado" in Physics at the University of Barcelona. During those years in the university he became aware that the scientific level of physics in Spain was low. He decided to pursue a doctoral degree abroad. He received several offers and elected Harvard.

The period 1956–1961 is almost certainly the most important in his life. On one side he obtained his Ph.D. degree at Harvard under the supervision of William Paul but even more important he found Inge, his wife and friend forever. Inge is an exceptional woman that made possible the full time dedication and success of Manuel in science. Inge not only took in her hands the organization their family's daily activity but she has been the dedicated hostess that made the visits of many students and colleagues that often went through Cardona's home so especially enjoyable.

Cardona devoted most of his life to the experimental and theoretical study of semiconductors and high temperature superconductors through the analysis of optical spectroscopic data. During his years at RCA and Brown University (1962–1971) Cardona became also active in the study of thermodynamic properties of low temperature superconductors. After his Ph.D. graduation at Harvard, Cardona accepted a research position at RCA laboratories, in Zurich (1959–1961) first to be continued in Princeton New Jersey (1961–1964). During this period Cardona concluded that the research of optical properties of semiconductors was near saturation. At the same time, he considered understanding the behavior of superconducting materials an intellectual challenge.

As later demonstrated while studying superconductivity, unexpected experimental results induced the discovery of a different type of superconductors. In contrast with the full flux expulsion recognized in Type I superconductors, the compatibility of the superconducting condition in some materials with partial magnetic field penetration was observed. Those materials were named Type II superconductors. The theoretical explanation of the new phenomenon was given by A.A. Abrikosov in 1957 introducing the concept of vortex lines.

During his stay at RCA, Cardona and collaborators analyzed the nature of the electronic states in the core of the vortices. Their microwave absorption experiments provided evidence that the energy dissipation associated with the vortex core was intrinsic to the new superconducting state and should not be linked to thermally induce electronic excitations. As a result, Cardona and collaborators were among the first to suggest that the specific heat of Type II superconductors should evidence a linear temperature dependent contribution associated with electron states in the vortex core, which was subsequently confirmed experimentally. This was quite a relevant contribution to the understanding of what we now consider "traditional" superconductivity. Cardona and collaborators were also able to detect the predicted nucleation of surface superconductivity in Type II superconductors when the magnetic field is applied parallel to the surface of the material.

Once at Brown (1964) Cardona decided to go back to studying the optical properties of semiconductors but now through optical modulation techniques,

increasing notoriously the sensitivity for detection of the optical spectra of semiconductors. Cardona and his team researched superconductivity studying metastable supercooling and superheating states of Type I superconductors in the presence of magnetic fields on parallel tracks. These experiments were continued until the beginning of the seventies providing valuable data on the superconducting parameters characterizing Type I superconductors.

In 1965 Cardona accepted an invitation from the University of Buenos Aires as a scientific advisor for a program supported by the Ford Foundation dedicated to modernizing the experimental facilities of the Physics Department. Cardona and Inge spent 3 months in the winter of Argentina. This was his first of many deep contacts with Latin American scientists, students and friends. Manuel and Inge felt quite pleased with the atmosphere and friendship found in Buenos Aires. The connections created by Manuel and Inge in Argentina and extended later to all Latin America, have been very important then and in the years that followed. At that time, Argentina was under a democratic regime. Cardona used to say that it was his first experience living in a democracy "in Spanish".

While in Buenos Aires, Manuel made a short visit to the Instituto de Física de Bariloche (today Instituto Balseiro) establishing contact with me and María Elena, my wife. We were both working on our Ph.D. thesis in the Low Temperature Laboratory, where a few years earlier (1961–1962) John Wheatley had established a research program in solid state physics. Manuel's presence in Bariloche was to our family the beginning of a lasting friendship. I explained to Manuel that I was researching transport properties of metals at low temperatures for my Ph.D. thesis. His interest, questions, recommendations impressed me very much. We started talking in the morning and late in the afternoon María Elena told us to go home for dinner. The three of us had a long after supper talk. We were much impressed by the general knowledge of this young physicist. No doubt the fact I was born in Barcelona during the Spanish civil war, staying in Barcelona until I was 13, was a topic for long remembrance. Cardona offered me help when looking for a post-doctoral position.

Several of Cardona's students at Brown at the end of the sixties were Argentineans. This was the result of his short and fruitful visit to Argentina and quite ironically "stimulated" by the military takeover of the Argentinean government at the beginning of 1966, a few months after Manuel ended his "sejour" in Buenos Aires. Cardona followed with concern the perils encountered by researchers and students in Buenos Aires. He was of great help offering openings for graduate students in his lab at Brown University as well as looking for open positions in USA and abroad for a good number of students and researchers that suffered the persecution of the military regime. Cardona's involvement when political turmoil affected life of ordinary citizens was a constant in his life. He and Inge frequently opened their house and resources to mitigate the anguish of suffering people.

During the sixties at Brown, Cardona recognized the great opportunity triggered by the application of modulation spectroscopic techniques studying the dielectric function of semiconductors. As a consequence, while continuing research in superconductivity, he decided to invest most of his efforts and resources in the

study of semiconductors. A good number of today's well respected Argentinean physicists in the area of semiconductors have been trained or collaborated with Cardona as a result of the strong scientific and human relation the Cardonas maintained with Argentine physicists since their first visit to Argentina.

After finishing my Ph.D. in Bariloche in 1968, I received an offer from Cardona for a post-doctoral position in his laboratory. Manuel gave me the opportunity to choose the area in which I would be working. Thinking in going back to Bariloche after finishing the post-doctoral training I decided to work in superconductivity since most of the necessary infrastructure was available there.

While in Providence the Cardona and de la Cruz families became very good friends. Since then our families have remained very close, in spite of time and distance. Our children, now grown up, keep memory of the good time they spent together. I was a few years younger than Manuel but many years behind in knowledge and experience. I learned from Manuel scientific integrity and commitment to students with diligence and dedication.

Cardona and family left Providence in 1970 and the de la Cruz family returned to Bariloche in 1971. Since then we have kept frequent contact either personally in Germany or Argentina or by phone calls. Of course, we miss Manuel but his presence remains among us.

Back in Bariloche, Maria Elena and I joined the Low Temperatures Laboratory. As a result of the experience gained with Cardona at Brown we initiated research in Type I and Type II superconductors first and in high temperature superconductors, later. Our interaction and collaboration with students from the Physics Department of the University of Buenos Aires stimulated a program of research in the same laboratory where Manuel had spent time in the 1960s. In this way his contributions, some years earlier, were in some way recovered and superconductivity and low temperature physics restarted in the Buenos Aires group. Today Bariloche and Buenos Aires have well established low temperature laboratories. In one way or another Cardona made a relevant contribution for their respective successes.

The use of spectroscopic techniques to understand the physics of materials was delayed many years in Bariloche as a consequence of lack of economical resources. It was only in the eighties when two excellent young physicists that received training from Manuel at the MPI in Stuttgart installed a facility that is recognized today as an excellent laboratory at the international level.

Finishing our rather incomplete description of Manuel extraordinary dedication we quote The "John C. Wheatley Prize" of the APS citation when awarded to Cardona in 1997:

> For being a dedicated mentor and guide to a whole generation of Latin American physicists and playing a decisive role in the development of physics in Latin America. By example, enthusiasm and very exacting standards he has inspired a respect for excellence and collegiality which now motivates many groups throughout Latin America.

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