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A LOOK AT PHYSICS IN CUBA
ADVANCED RESEARCH IN A DEVELOPING COUNTRY

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When the Soviet Union collapsed, many people expected that Cuban social organization, scientific structure and higher education system would have not survived for a long time. This did not happen. No doubt that the new situation had a negative impact on the development and organization of scientific research and teaching, but Science, and Physics in particular, have not collapsed, and have even registered some progress. Reports about Physics in Latin America place Cuba (a country with 11 million inhabitants) among the countries with an intermediate number of PhDs in Physics (between 100 and 500) together with Chile, Venezuela and Colombia, and behind Brazil (3000), Mexico (2200) and Argentina (2000) with much larger populations. Moreover, the University of Havana is among the more representative institutions for the development of Physics in the region[1] and the importance of contributions of Cuban physicists in areas like Condensed Matter, Material Physics, Solar Energy, Optoelectronics and Medical Physics is recognized.

From 1960 to 1990 about 1300 Cubans graduated in Physics (836 of them at Cuban Universities) and a similar number of Secondary School Physics Teachers graduated at the Higher Pedagogical Institutes. The number of physicists with a PhD degree registered in 1990 by the National Commission of Scientific Degrees was 129, about 10% of the total number of physicists. At that time, this number was growing at a rate of around 10 new PhDs per year. In the nineties, 518 new physicists and 58 PhDs (not dramatically less than the 103 of the eighties) graduated in Cuba. However, new M.Sc. programs in Physics, which had an ephemeral existence in the seventies, were launched in 1994 and have since produced 108 specialists in different branches of pure and applied Physics.

In the decade 1991-2000 a critical mass of scientists and technologists in a consolidated scientific and higher education system, allowed Cuban science and technology to resist the impact of the Soviet Union collapse and to overcome obstacles that appeared to be insurmountable. It is important to note that Physics is a small sector of Cuban Science when compared to Biotechnology and other branches of biomedical research.

1 Morán, José Luis, (2000), "Physics in Latin America Comes of Age", *Physics Today*, 2000, *Vol.* 53, No. 10, p 38.

Very little has been published about the development and standards reached by Physics in Cuba. In order to understand the events of the last 15 years, the present situation and its future perspective it is first necessary to briefly review the main facts and results of Cuban Physics until 1990 in terms of both professional level and soundness of the infrastructure.

1. THE BEGINNINGS[2]

Until the fifties the standard of studies in Physics in Cuba was quite poor. Under the colonial rule, Teaching of Physics was introduced by the priest Félix Varela around 1814 under the late influence of Enlightenment.[3] At that time the University of Havana, founded in 1728, maintained a substantially Aristotelian structure until its secularization in 1842. Physics teaching conserved an essentially descriptive character until the first decades of the 20th Century. It was in 1923, in the framework of a general social and cultural ferment, that Manuel Gran introduced a more consistent and rigorous approach to the teaching of Physics, with suitable mathematical background, problem solving and practical experiments. In 1933 a course of Theoretical Physics was introduced while the University offered degrees in Physical-Chemical Sciences and Physical-Mathematical Sciences. However, Physics teaching remained confined to the formation of secondary school teachers and did not include modern physics. There was basically no scientific research. In the fifties, Marcelo Alonso introduced early notions of quantum physics and started some activity in Nuclear Physics[4].

In the sixties, a radical transformation of education, science and culture was undertaken. A general campaign to eliminate illiteracy in the whole country took place in 1961. The 1962 University Reform paved the way to the development of a modern higher education system in which scientific research, both pure and applied, played a fundamental role. A Faculty of Sciences with seven independent Schools of Physics, Chemistry, Mathematics, Biology, Pharmacy, Geography and Psychology was created at the University of Havana in 1961. Relatively soon after that, in the period 1967-1980, a solid output of qualified graduates provided the human resources for the development of a modern research system.

2. THE RAISE OF PHYSICS AT THE HAVANA UNIVERSITY

From the very beginning the School of Physics (*Escuela de Física*, EF) faced enormous problems, due to the dramatic lack of laboratories, equipments, scientific information and trained personnel. In 1961 a first group of Cuban students moved to the USSR to graduate in its higher education institutions: many of them studied Physics and then joined the staff of the EF in the second half of the sixties. The support of foreign collaborators was extremely important in the initial phase of the EF. Physicists from the Soviet Union contributed mainly to the organization of teaching. In addition, several invited professors from "western" countries (United Kingdom, Israel, France, Argentina, Italy, Mexico, and the United States) came to Cuba for periods, from one to several years, teaching courses in modern physics, and helping in building new laboratories in Acoustics, Electronics, and Solid State Physics. Very important was also their contribution to the creation of workshops of Electronics, Mechanics and

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[2] Baracca, Angelo; Altshuler, José, (2004), "La enseñanza de la Física en Cuba, desde la Colonia hasta 1959", *Llull* (Zaragoza), 2004, *27*, pp. 557-608.

3 Varela, Félix, (1813), *Instituciones de Filosofía Ecléctica,* La Habana, Imp. de Palmer e hijo.

[4] Altshuler, José, (1989), *Estudios de Historia de la Ciencia y la Tecnología*, Editorial Academia, La Habana, Cuba (1989), p.11.

Glass Manufacturing for the construction of scientific instruments playing a decisive role in the priority given to the development of experimental physics. Among the invited scientists was Andrea Levialdi, an Italian physicist who died in Cuba in 1969. In his memory, the "Levialdi Scholarship" was created for postgraduate training in Parma, initiating a long lasting collaboration with Parma University and MASPEC Laboratory, where about 20 Cuban physicists have been trained since 1970. In the sixties, the best Soviet and American Physics textbooks, either in English or translated into Spanish, were printed for student use.

The choice of the kind of Physics most suitable to the needs of the country raised a lively debate among the professorship at the UH. The plans for the industrial development of the country assigned an important place to Electronics and Metallurgy. In 1968 the discussion followed with French and Italian physicists (Vigier, Fieschi, Amati) in the Havana Cultural Congress, where the decision was taken of organizing Summer Schools, that took place till 1973 with strong participation of European professors (even 172, in different fields) and Cuban fellows (around one thousand). These debates led to the decision of concentrating almost all research efforts of the EF to Solid State Physics and Electronics. In 1967 the first germanium diode "made in Cuba" had been performed at the EF[5], marking the official birth of research in Solid State Physics.

New teaching and research institutions with ties to Physics were created in the Havana University. Since 1964, the Faculty of Technology had moved to the new campus of the University City José Antonio Echevarría (CUJAE became an independent university in 1974). The Center for Digital Research (CID), where the first Cuban computers were built also initiated its activities in the sixties. The National Center for Scientific Research (CNIC) was inaugurated in 1965 and began to work with a wide autonomy and to direct government support for the development of scientific research and to promote postgraduate training. CNIC´s activities focused mainly on biology, chemistry and agriculture, including Physics as a supporting discipline.

At the beginning of the seventies the Physics Bachelor program was consolidated and teaching laboratories of Mechanics, Molecular Physics, Electromagnetism, Electronics, Optics, Atomic, Nuclear and Solid State Physics for undergraduate studies had been built and equipped. The graduation of more than 100 physicists at the EF in 1970 and 1971 provided a "critical mass" that allowed to cover the lack of Physics Teachers at Cuban universities and to devote more people, time and resources to scientific research and postgraduate education. About 50 physicists got a M.Sc .in Solid State Physics at the EF from 1972 to 1977. For the first time a large international meeting in Physics, the IV Latino American Symposium on Solid State Physics, was organized in 1975 with great success and local impact. Scientific collaboration with Soviet institutions, in particular with Moscow University and the "Ioffe" Institute Physical Technical Institute of Leningrad, grew stronger. Undergraduate education of physicists at Soviet universities continued with postgraduate training and joint research activities being the main forms of cooperation.

In 1969 a crucial change took place when French physicists introduced silicon-based devices at a Summer School. A Planar Technology Laboratory (LTP) was established in the UH, and a similar Microelectronic Research Center (CIME) in the CUJAE, related with the project of a pilot plant for the production of semiconductor devices. MOS and other integrated circuit and silicon solar cells were developed, and the first pilot plant was settled. Around the mid-seventies, in a very short period

[5] Crespo, Fernando; Vigil, Elena; Waisman, Dina (1968), *Conferencia Química de Oriente* (Santiago de Cuba: 1968).

indeed, a good level of integrated microelectronics, relative to Latin America, had been achieved.

In 1962 the Cuban Academy of Sciences (ACC) was created, to promote scientific development. Several new sectors were established[6]: Meteorology, Geophysics, Astrophysics and Electronics started soon in the Academy of Sciences as working groups or departments and consolidated as Institutes during the seventies. Collaborations with, and support from specialists and the leading scientific institutions of the Soviet Union and the Socialist Countries allowed the realization of important facilities and services. These included artificial satellite tracking and monitoring (connected with the Moscow Cosmos Center), the Cuban meteorological service (of the utmost importance in a tropical country), improvements in communications and seismic, magnetic and gravimetric detection.

The early Electronics Group grew into the Institute for Fundamental Technical Research (ININTEF), a multi-disciplinary and flexible institution devoted to the development of basic and applied fields like ultrasonic, high-precision clocks, remote sensing, solar energy, electric networks, holography and stochastic processes. The ININTEF generated other centres such as the Institute of Solar Energy in Santiago of Cuba, in 1982.

Activities in Nuclear Physics by the Academy of Sciences grew up from an initial Study Group in 1966 and promoted the birth of the Institute of Nuclear Physics in 1969, later renamed as Nuclear Research Institute (NRI) in 1974. Equipped by the Soviet Union with a sub-critical reactor, neutron and gamma detectors, analyzers and radiochemical facilities, the NRI established collaborations with the Soviet Atomic Energy Commission and the Dubna Nuclear Research Institute.

Research in Optics and Optoelectronics began at the end of the sixties at the Havana University. In the Military Technical Institute, established in 1967, the first CO_2 laser was designed and built in Cuba (1974). In the School of Physics of the Oriente University, created in 1970 and mainly devoted to applied research, optical and spectroscopic techniques were developed together with other analytical methods[7].

3. THE MATURITY OF CUBAN PHYSICS BEFORE 1990

By 1990 the Universities of Havana (UH) and Oriente and the Higher Institute of Nuclear Science and Technology offered programs in Physics, with an overall average number of 50 graduates per year. The five-year curriculum, strongly influenced by the Soviet school, was characterized by a solid theoretical and experimental background and included research activities at an appreciable international standard. The Special Vocational Pre-university Institutes for Exact Sciences, spread all over the country, provided an excellent source of young students, well trained to enter scientific and technical careers. Some of these students had obtained remarkable results in national and international Olympiads in Physics,[8] Chemistry or Mathematics. Cuba was the first Latin American Country to organize an International Physics Olympiad (the 22nd IPHO was celebrated in Cuba in 1991). A national network of Higher Pedagogical Institutes prepared Secondary Schools Physics Teachers.

In the job market, physicists concentrated in the universities and the research

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[6] Ortiz, Humberto (1987), "Academia de Ciencia de Cuba", *Conferencias y Estudios de Historia y Organización de la Ciencia*, 1987, *53*, p.18.

[7] Baracca, Angelo; Méndez Pérez, Luis, (2001), "Cincuenta años de Física en la Universidad de Oriente (Santiago de Cuba)", *Revista Cubana de Física*, 2001, *18* (2), pp. 146-154.

[8] Sifredo, Carlos, (2004), *Memorias del II Simposio de las Olimpiadas Iberoamericanas de Física* (Salvador, Brazil).

institutes, with a growing presence in health centers and industry. About 40 research groups existed in pure and applied Physics. Experimental facilities were modest, but equipments and supplies were enough to work in Physics, Mathematical and Theoretical Physics. Cuban Physics was strongly connected with education at all levels, with health services and with two national programs of industrial development in the fields of electronics and nuclear energy, which were important drivers for research and training in physics. The most developed research areas were Solid State Physics, Nuclear Physics, Optics, Medical Physics, Mathematical and Theoretical Physics. Physicists were also very active in multidisciplinary groups of Meteorology, Geophysics, Astronomy, Microelectronics, Metallurgy, Metrology, Robotics, Informatics, Neurosciences and Molecular Biology. Most PhD degrees were obtained in Solid State, Materials and Nuclear Physics[9].

The Cuban Physical Society, created in 1978, had around 500 associates: since 1981 it published the *Revista Cubana de Física*, and organized a triennial symposium. International events were regularly organized in the country, and Cuban physicists actively participated in scientific collaborations with Soviet, European and Latin American Institutions. Besides there was an active participation in international organizations related to Physics like the Latin American Center of Physics (CLAF), the Latin American Federation of Physical Societies (FELASOFI), the International Center of Theoretical Physics (ICTP), the International Union of Pure and Applied Physics (IUPAP), the International Atomic Energy Agency (IAEA), the Intercosmos Program, the International Commission of Optics (ICO) and others.

Starting from the level reached by the Cuban scientific system in the previous decade, the eighties brought on a strengthening of research activities in Physics, due to the foundation of new research centers and further incentive and renovation of already developed fields of interest. A special effort was devoted to the reinforcement of nuclear physics and technology in view of the construction of the first electro-nuclear plant in the country, in Juraguá, under the contract subscribed in 1976 with the Soviet Union. The choice of developing this field with some autonomy with respect to the body of the Cuban scientific system, and the huge human and economic resources it absorbed, created some contrast with other fields of research that suffered limitations. In 1980 the Cuban Atomic Energy Commission and an Executive Secretary were created. A specific Faculty was created in the Havana University, evolving into an independent Higher Institute of Nuclear Sciences and Technologies in 1987, devoted to the training of high-level nuclear physicists and engineers. In 1986 the ININ grew into the Center of Studies Applied to Nuclear Development (CEADEN), incorporated three years later in the Western Scientific Pole.

During the Intercosmos space flight that took place on September 18-26, 1980, with the participation of a Cuban cosmonaut, three experiments, out of the twenty or so then performed in orbit, were designed by Cuban physicists and engineers who worked for nearly three years in collaboration with Soviet scientists. One of the experiments was designed to obtain new semiconductor materials under microgravity, while the purpose of the other two was to study the effect of microgravity on the crystallization of an organic crystal (sucrose), including the molecular kinetics and crystal micro-topography. By the end of the year, two other experiments prepared in collaboration with the Ioffe Physico-Technical Institute of Leningrad, were performed on board the Salyut-6 orbital station. They dealt with holographic information transmission between the Salyut-6 station and earth. In March 1981, 3-D holographic picture sequences of the dissolution of a salt in a liquid

[9] De Melo,Osvaldo (2002), "40 años de la carrera de Física en la Universidad de La Habana. Pregrado y postgrado", *Revista Cubana de Física*, 2002, *19*, p. 30.

were taken in orbit for ground study of the dynamics of the process.

After the decline of the activities in microelectronics, due to the rapid progress in high integration that only few industrially developed countries could sustain, Cuban research was reoriented towards optoelectronic sensors and new materials. A National Program in Electronics was created in 1986 and the "Front for Electronics" coordinated all the institutions connected with the national electronic industry, informatics and industrial automation. The production plant of semiconductor components began to assemble equipment from imported chips in 1984, and produced some integrated circuit, although it never managed to work at the level it had been aimed to. In 1985 the Institute of Materials and Reagents for Electronics (IMRE) tightly bound to the Faculties of Physics and Chemistry was created at the University of Havana to work on materials, chemicals, lasers and optoelectronics, in support to industrial areas. In 1987 a high temperature superconductor ceramics was obtained in the UH, just six months after the discovery of the phenomenon. A Superconductivity Laboratory was subsequently created and has published more than 30 papers on international journals to date.

A Research Center on Solar Energy was created in Santiago de Cuba, pertaining to the Academy of Sciences and devoted to research in energy saving. In Eastern University (UO) activities were reoriented towards the nickel industry and an interesting activity in biophysics lead to the creation of a Center of Biophysics, an independent institute[10] that designed and constructed different versions of Magnetic Resonance Imaging facilities.

The Center for the Construction of Scientific Instruments, previously named Bureau of Construction of Scientific Instruments with Attached Production, was created in 1978 attaining the complete cycle of design and production of optical and scientific equipment. This allowed the construction of electronic equipment, lasers for physiotherapy and analytical instruments, which are usually produced in developed countries. Its first objective was to contribute, as long as others, in increasing the impact of Physics and Technology to the society.

It is important to mention again the Group of Theoretical Physics of the Institute of Cybernetics Mathematics and Physics, which devotes its activity to research in problems of quantum field theory and its applications in high energy physics and condensed matter. The Group has organized four Caribbean Workshops on Quantum Mechanics, Particles and Fields and a School on String Theory. The support of ICTP to its development has been essential.

4. The Last 15 Years

With the collapse of the Soviet Union, the whole Cuban scientific community suffered a tremendous drop of every kind of resources, both financial and material, and a shortage of international exchanges and scientific information. The national programs with the higher presence of physicists (electronics, nuclear energy) were reduced, while priority was assigned during the nineties to sectors less related with Physics, like tourism, food, biotechnology, medicine and pharmacy. Many institutions, groups and activities had to be redirected and reformed. In 1998 it was definitely decided to abandon the construction of the nuclear plant in Juraguá, interrupted after the collapse of the Soviet Union. This induced a redirection of research and teaching activities in Nuclear Science and Technology. Some research

[10] Baracca, Angelo, Fajer, Víctor; Henríquez, Víctor (2001). "The development of Physics in Cuba during the sixties and seventies of the XXth. Century: an integrated approach", *Proceedings of the XXI International Congress of History of Science*, (México, ed. Sociedad Mexicana de Historia de la Ciencia y la Tecnología, 2001), p. 15-25.

groups disappeared, other had to leave or reduce active research. The staff of the research centers and the universities was frozen, while the paralysis of industrial activities stopped the incipient presence of physicists in this sector. This induced in turn a contraction of student registration in Physics. The equipments in teaching laboratories aged and decayed. An estimated number of 200 physicists left the country, and an undetermined number shifted to activities other than Science, in search for better economic conditions. The average age of staff people grew. About half of present PhDs will have reached the age for retirement in 2010. Even with economic restoration initiated in 1997, demand towards research sectors in Physics have been feeble, and mainly of a short-term kind. Long-term programs have been difficult to develop, and Physics have stood fairly behind with respect to priorities of Cuban science.

This situation obviously affected all the activities in Physics, but the critical mass achieved of physicists with a graduation or a PhD, and the stability reached in this field allowed to resist and overcome the difficult situation.

Notwithstanding, some impulse was given to activities in renewable energies and environment, computing capacities have been increased, in spite of shortage of powerful machines for scientific computing. Growth of informatics and communications improved access to up-dated technical and scientific information. This progress induced the shift of several experimental activities towards simulations and modeling. Such contributions have been important, but they have modified the equilibrium between theoretical and experimental activity. Nevertheless, various teams have given contributions to the solution of problems of the country designing and constructing medical and analytical equipments, giving technical and scientific services to industry or generating new products.

Cuban physicists had benefited from access to the highest Soviet scientific institutions, but it was now the turn of the contacts they had previously established and maintained with "Western" countries and institutions to become extremely useful. Scientific exchanges and collaborations shifted mainly towards Spain, Italy, Germany and Latin American countries. Of the latter, Mexico and Brazil have a leading role. The collaboration with the ICTP in Trieste has also been very important. In the 2000 year, contacts with the American Physical Society were established and resulted into exchange right agreements with the Cuban Physical Society, and in the performance in Havana of meetings on Medical Physics and Physics Teaching, with large participation of Physicists from USA. An important role in obtaining these results was played by Leon Lederman and Irving Lerch among others. Exchange Right Agreements have been extended to all Iberoamerican Physical Societies.

5. PRESENT AND FUTURE

The new century began with stimulating signals for the recovery and advance of Cuban Physics. According to the relevance assigned to Medicine in Cuba, Medical Physics is one of the branches with more perspectives: investments around 400 million dollars in medical equipments has been recently performed. At present there are more than 75 physicists working in clinical environment, 32 of them in Nuclear Medicine, 28 in Radiotherapy, and the rest in Diagnostic Imaging and Radiation Protection. New equipment of Radiotherapy and Nuclear Medicine will be installed [10 new linear accelerators applied to radiotherapy and radio-surgery, 4 new units of cobalt therapy, several double headed gamma cameras, 40 Computer Tomography (CT)-simulators], requiring at least another 20 physicists more in those areas. Diagnostic imaging will be reinforced, with the installation of 8 new Magnetic Resonance Imaging (MRI) facilities. A Master degree in Medical Physics is in its first course with 25 students; a higher degree specialization in Radiation Oncology

Physics is also training specialists in that field; a degree in Health Technology has been created, with a specialty in Medical Radiophysics (equivalent to Dosimetrist), with 100 students subscribed.

More than 24 excimer laser systems for refractive surgery and other high technique optical instruments for ophthalmology have been bought, in a plan for giving services to Cuban and Latin American patients all over the country. The maintenance and secure application of this technique originate new jobs for physicists and engineers.

New instruments conceived and designed by teams directed by Cuban physicists will continue its introduction in Cuba and abroad. Creation of a network of images for MRI instruments[11] will be performed. Equipments for clinical analysis and analytical chemistry will also be improved, such as microfluorimeters and spectrophotometers of the SUMA series for early detection of congenital diseases, and diagnosis of hepatitis, AIDS and other diseases. Medical instruments employing lasers for physiotherapy and laserpuncture will be incorporated in primary attendance. New versions of automatic laser polarimeters will be developed for the sugar, pharmaceutical and food industries, and will also be included in chromatographic systems for biotechnology.

Condensed matter is the field in which the majority of Cuban physicists is still employed. A National Program for Scientific Research and Innovation on New and Advanced Materials approved in 2003 gives priority to research in this field, with emphasis on nanomaterials.

In the field of nuclear physics, radiation-matter interactions will be studied for the modification of solid materials. Cuba entered as member 29 in the ALICE project in high energy physics at CERN (Geneva) taking part in its experimental and theoretical work.

Physicists have played a very important role in establishing and developing meteorological services in Cuba. This sector is being strengthened with important investments in modern equipment and this will result in a new stimulus for Physics. Also the field of renewable energies, where physicists have always had an important contribution, is expanding at present. There is a plan for installing eolian power stations for producing 100 MW.

During the past 40 years physics teaching has been subject to a systematic and intensive improvement in Cuba, reaching important goals. Nevertheless a small reduction in teaching hours of this discipline in Secondary Schools has taken place, and the lack of teachers has affected quality: an attempt to compensate these short backs conceives the introduction of a large use of television classes and other modern teaching techniques.

At the universities the number of Physics students is increasing slightly, the studies of Physics have been extended to the Central University “Martha Abreu” and a new program on “Physics Engineering” is about to be created.

[11] Cabal, Carlos, (2002), *Cuba, Amanecer del Tercer Milenio. Ciencia, Sociedad y Tecnología* (La Habana: Editorial Científico-Técnica, 2002).