feature article

A look at physics in Cuba

Angelo Baracca, Víctor Fajer, and Carlos Rodríguez

Some people might believe that the history of physics in Cuba is like that of many other countries, except for the Soviet influence on a socialist country during the cold war. The full story is very different.

Angelo Baracca is an associate professor of physics at the University of Florence, Italy. **Víctor Fajer** is a member of the Cuban Academy of Sciences and heads the instrumentation development division of the Center of Applied Technologies and Nuclear Development in Havana, Cuba. **Carlos Rodríguez**, also a member of the Cuban Academy of Sciences, is director of the University of Havana's Institute of Materials and Reagents.

The history of physics in Cuba is intimately connected to Cuba's relationships with the Soviet Union, other socialist countries, and other parts of Latin America and Europe. But the history also reflects the strength, character, and resilience of the Cuban people.

A Spanish colony until 1898, Cuba formally gained independence in 1902. Growing social ferment resulted in the revolution that overthrew Fulgencio Batista in 1959. The new government promoted deep and ambitious changes in every aspect of society and encouraged modernization and the development of science and industry. In 1961, a general campaign of widespread mobilization eliminated illiteracy from the country. An advanced system of research and higher education was built up in the following decades.

That growth was an extremely difficult task. Since 1960, collaboration with socialist countries—particularly the Soviet Union—played an increasing role, one whose relevance can hardly be overestimated. But many scientists invited from nonsocialist countries also visited Cuba on an individual, voluntary basis and helped enormously in building a modern system of higher education and in promoting scientific research. The construction of Cuban science grew through the interplay between high-level government authorities and the scientific community. Students also played an active role.

The Cuban government and Cuban scientists have tried to build a balanced and cross-disciplinary system of sciences. The guiding principle has been connecting the development of science to the concrete needs of the country. A typical example is the close collaboration between meteorological institutes and civil defense; such ties make it possible to avoid the worst consequences of hurricanes and other natural catastrophes. Another example is the collaboration between biotechnological research and the public health system. Not only have applied fields been developed, but also the fundamental fields of pure physics and other basic sciences.

The collapse of the Soviet Union in the early 1990s presented a serious challenge to Cuban science and education, but in those areas—and particularly in physics—Cuba has survived and even made some progress. In 2000 Cuba (a country with 11 million inhabitants, a population comparable to that of metropolitan New York City), as well as Chile, Venezuela, and Colombia, was among the Latin American countries with an intermediate number of PhDs in physics (between 100 and 500) compared to Brazil (3000), Mexico (2200), and Argentina (2000). (See the article "Physics in Latin America Comes of Age" by José Luis Morán-López, PHYSICS TODAY, October 2000, page 38.) The University of Havana (UH) is among the outstanding institutions in the region for the advancement of physics, and Cuban physicists have made valued contributions in such areas as condensed matter and materials physics, solar energy, optoelectronics, and medical physics.

From 1960 to 1990, about 1300 Cuban physicists graduated—two-thirds of them from Cuban universities, the others from foreign institutions, mainly in the Soviet Union and other socialist countries—and a similar number of secondary-school physics teachers graduated from Cuba's higher institutions of pedagogy. The number of PhDs in physics registered in 1990 by the National Commission of Scientific Degrees was 129, about 10% of the total number of physicists, and the number was growing by about 10 PhDs per year. In the 1990s, 518 bachelor's degrees and 58 PhDs were awarded in physics in Cuba. In addition, MSc programs in physics, which had an ephemeral existence in the 1970s, were relaunched in 1994 and have produced 108 specialists in different branches of pure and applied physics.

Little has been published about the development and achievements of physics in Cuba.[1] To understand its development, one needs to start by examining its origins.

Beginnings

Until the 1950s, physics was studied to only a small extent in Cuba. Although the first studies in the field were introduced in 1814 by a priest, Félix Varela, under the late influence of the Enlightenment,[2] an Aristotelian attitude and curriculum dominated at UH (founded in 1728) until the secularization of the university in 1842. Still, the teaching of physics remained essentially descriptive until the first decades of the 20th century. It was not until 1923, amid general social and cultural ferment, that Manuel Gran introduced a more substantial and rigorous approach to physics education, with due mathematical preparation, problem solving, and practical experiments. In 1933, when the university offered degrees in physical and chemical sciences and in physical and mathematical sciences, a course in theoretical physics was introduced. However, the teaching of physics was still confined to the training of secondary-school teachers and did not include modern physics. Little if any scientific research took place. In the 1950s, Marcelo Alonso introduced basic notions of quantum physics and started some teaching of nuclear physics.[3]

Starting in 1959, Cuba's new government assumed the explicit goal of developing science as a fundamental factor in

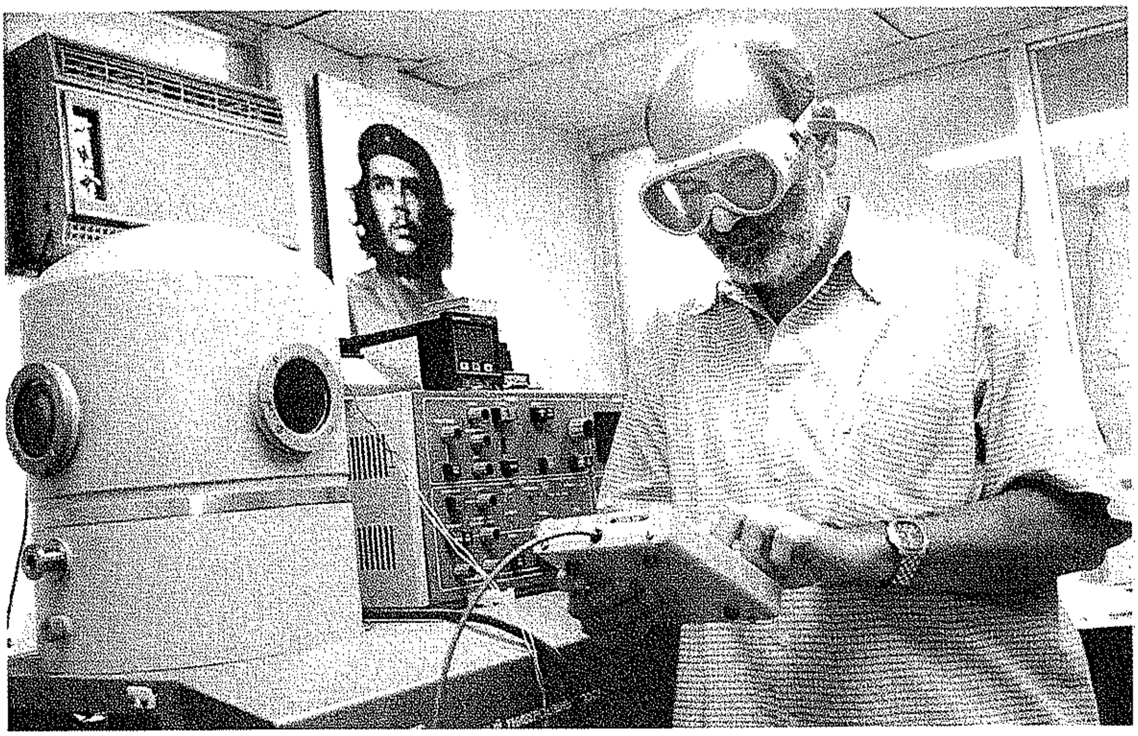


Figure 1. A pulsed laser deposition system in the Institute of Materials and Reagents (IMRE) of the University of Havana. IMRE was established in 1985 to support industrial needs for materials, chemicals, lasers, and optoelectronics. This system allows laser deposition and in situ studies of high-T_c superconductors, manganites with colossal magnetoresistance, and other thin-film oxides.

the creation of a modern and equitable society. The social situation was characterized by new forms of participation. The student movement, which had actively taken part in the revolution, was particularly involved in the renovation of university structure and curriculum and in teaching. The teaching staff was, in fact, largely depleted, as many left for economic or political reasons following the overthrow of Batista, US sanctions, and the Bay of Pigs invasion. An early effort of profound modernization took place in 1960 in UH's faculty of electrical engineering, as students took autonomous action and, with the help of a few teachers, copied the most advanced physics textbooks from the US to overcome serious shortages.

The 1960s saw a radical transformation of education, science, and culture. The 1962 university reform, developed by a commission composed of professors and students, paved the way for the development of a modern system of higher education in which scientific research, both pure and applied, played a fundamental role. A faculty of sciences with seven independent schools—physics, chemistry, mathematics, biology, pharmacy, geography, and psychology—was created at UH in 1961. Soon thereafter, a solid output of qualified graduates began to provide the human resources for the development of a modern research system.

The "romantic period"

From its beginning, UH's school of physics (Escuela de Física, EF) faced enormous problems, due to the dramatic lack of laboratories, equipment, scientific information, and trained personnel, not to mention scanty organization. Professors and students employed in teaching had ample room to take initiative.

Ernesto "Che" Guevara himself, at the time the minister of industry, seized an early opportunity in 1961 and sent a first group of Cuban students to the Soviet Union for their higher education; six of them graduated in physics and returned to join the EF faculty. A substantial and steadily growing flow of students to the Soviet Union developed in subsequent years.

In 1962, a small number of physicists from the Soviet Union began visiting Cuba, contributing mainly to the organization of the teaching program. In addition, a number of visiting professors from nonsocialist countries—the UK, Israel, France, Argentina, Italy, Mexico, and the US—came to Cuba during the 1960s for periods ranging from one to several years. They taught courses in modern physics; promoted the creation of new laboratories in acoustics, electronics, and solid-state physics; and set up workshops in electronics, mechanics, and glass manufacturing for the construction of scientific instruments. They were a deciding factor in Cuba's choice to support the development of experimental physics. In memory of Italian physicist Andrea Levialdi, who died in Cuba in 1969, the Levialdi Scholarship was created for Cuban physics graduates to receive postgraduate training in Parma. A long-lasting collaboration with the University of Parma and with Parma's MASPEC (Special Materials) Institute (now part of the Institute of Materials for Electronics and Magnetism) has since developed. Also during the decade, the best Soviet and US physics textbooks were printed in Cuba in either English or Spanish.

The EF's move to a larger building in 1967 allowed the expansion of existing laboratories and the construction of new ones. A lively debate ensued, mainly among professors and students supporting teaching and research activities, about which fields of physics would best meet the needs of the developing country. The discussion partly reflected high-level opinions. Guevara, for instance, thought that solid-state electronic devices would play a crucial role in the future and that Cuba could offer an original contribution among socialist countries. The 1967 demonstration of the first Cuban-made germanium diode at the EF marked the official birth of research in solid-state physics. French and Italian physicists who participated in the 1968 Havana Cultural Congress supported the focus on solid-state physics, and the EF decided to gradually concentrate research activities on that and related fields, such as electronics, optics and optoelectronics, and atomic physics.

Plans for the country's industrial development emphasized electronics and metallurgy but based their application

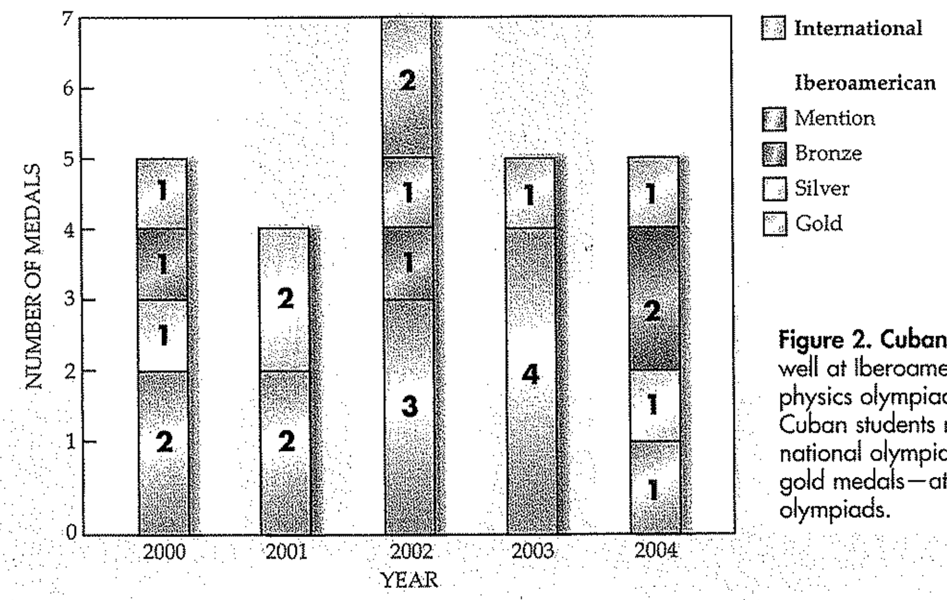


Figure 2. Cuban students have performed well at Iberoamerican and international physics olympiads. From 2000 to 2004, Cuban students received 5 medals at international olympiads and 21—including 12 gold medals—at the Iberoamerican olympiads.

on sound fundamental research. A department of solid-state theoretical physics began to take shape in the EF. French and Italian scientists promoted summer schools in Cuba, where they held advanced courses and brought materials and equipment. Additionally, the need for the advancement of other fields was clearly perceived, and other institutions were soon created to establish a balance among scientific disciplines.

The Cuban Academy of Sciences (ACC), revitalized in 1962 and assigned new tasks, played an important part in promoting scientific development in several fundamental branches. Meteorology, geophysics, astrophysics, and electronics were soon established as work groups or departments in the ACC and were consolidated as institutes during the 1970s. The Institute of Nuclear Physics was inaugurated in 1969, and in the 1970s new physics faculties were created at Oriente University and the Central University of Las Villas. Meanwhile, collaboration with and support from leading scientists and institutions in the Soviet Union and other socialist countries led to the development of important facilities and services, such as the artificial satellite tracking and monitoring system (connected with the Moscow Cosmos Center) and the Cuban meteorological service (crucial in a tropical country), and improvements in communications and seismic, magnetic, and gravimetric detection.

After the first Cuban physics graduates returned from the Soviet Union in 1967, a stable curriculum was set up in the EF in the early 1970s, and undergraduate teaching laboratories for mechanics, molecular physics, electromagnetism, electronics, optics, and atomic and solid-state physics were established. More than 100 physicists graduated with BS degrees from the EF in 1970 and 1971 and provided a critical mass to eventually fill the physics professorships at Cuban universities and to devote more people, time, and resources to scientific research and postgraduate education. About 50 physicists went on to receive MSc degrees in solid-state physics from the EF between 1972 and 1977.

The growth of microelectronics is a good example of the development of research in Cuba. After French physicists introduced silicon planar technology in a 1969 summer school, Cuban physicists quickly began developing it. Metal oxide semiconductor and other integrated circuits and silicon solar cells were fabricated, and basic studies advanced. By the mid-1970s, a pilot plant for producing semiconductor devices had been built, and in the area of microelectronics at an intermediate integration scale, Cuba had reached high proficiency relative to other Latin American countries.

In 1973 the first laser built entirely in Cuba was constructed. And in 1975, Cuba hosted its first large international meeting in physics, the fourth Latin American Symposium on Solid-State Physics. But unfortunately, successful advancement in microelectronics was soon to be thwarted in Cuba—and in other developing countries—by rapid progress in large-scale integration, which only industrially developed countries could sustain.

Scientific collaboration with Soviet institutions increased, particularly with Moscow State University and the Ioffe Physico-Technical Institute in Leningrad. Undergraduate training of physicists at Soviet universities continued, but the main forms of cooperation became postgraduate training and joint research. The growing ties, mainly in the ACC, with socialist countries were becoming crucial for the development of other fields, particularly nuclear physics: Besides receiving support in teaching and training, Cuban efforts in that field benefited from the introduction of experimental equipment and techniques through collaboration with the Soviet Atomic Energy Commission and the Joint Institute for Nuclear Research in Dubna.

Meanwhile, radiotherapy services were becoming available all over the country, starting in the 1960s with a group of physicists working at the Havana Oncological Institute and, by the end of the 1970s, reaching a total of about 30 medical physicists, a considerable number for a small developing country.

The Center for the Development of Scientific Equipment and Instruments was created in 1978 out of previously existing entities to realize a complete cycle in the design and production of optical and scientific equipment—electronic devices, lasers for physiotherapy, and analytical and other instruments ordinarily produced in developed countries—and to reinforce the impact of physics and technology on society. In the second half of the 1970s, government consolidation led to the institutionalization of higher education and research and to the establishment of the Ministry of Higher Education. The result was a new phase of greater opportuni-

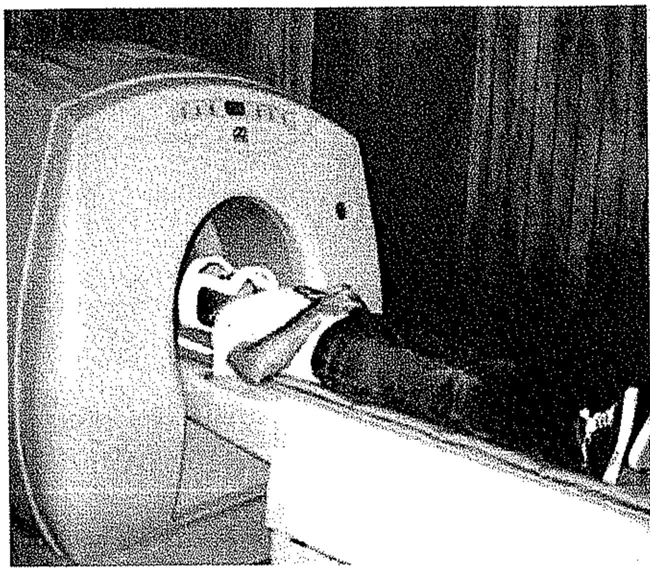


Figure 3. Medical physics is an increasingly important area of physics activity in Cuba. This whole-body magnetic resonance imaging system was designed and constructed by the Center for Medical Biophysics at Santiago de Cuba. Operating at a low field intensity of 0.1 tesla, it has been in service since 2001 in the clinical hospital of Holguín, an eastern province of Cuba.

ties and resources, although in some sense it brought to a close the "romantic" period of lofty goals unfettered by limited resources and organization.

Growth in the 1980s

Building on the level achieved by Cuban science in the previous decade, the 1980s brought a substantial increase in physics research activities, due in part to the foundation of new research centers. There were also further renovation and greater incentives, including better infrastructure for doing physics and organized collaboration possibilities.

The government's decision in 1976 to build the country's first nuclear power plant, in Juraguá under a contract signed with the Soviet Union, reflected a special effort to promote nuclear physics and technology. The choice to develop that field with some independence from the whole of Cuban science, and the huge human and economic resources the effort absorbed, created some tension with other fields of research. In 1980 the Cuban Atomic Energy Commission was created. Construction of the Juraguá plant began in 1983. The Higher Institute of Nuclear Sciences and Technologies (ISCTN), devoted to the training of high-level nuclear physicists and engineers, and the Center of Applied Technologies and Nuclear Development were created in 1986–87 from previously existing institutions. A network of centers—one for production, two for research, one for information, and one for radiological-waste management—was created as part of Cuba's Atomic Energy Commission.

From 1978 to 1988, the Soviet Union's Intercosmos Program provided socialist countries with opportunities to participate in space exploration. As part of that program, Cuban cosmonaut Arnaldo Tamayo Méndez participated in the flight of *Soyuz 38* on 18–26 September 1980. Out of the 20 or so experiments performed on that mission, 3 had been designed by Cuban physicists and engineers, who had worked for nearly three years in collaboration with Soviet scientists. One of the experiments was designed to obtain new semiconductor materials under microgravity. The other two studied the effects of microgravity on the crystallization of an organic crystal (sucrose); those experiments, which included looking at the molecular kinetics and crystal microtopography, had applications in the sugar industry. Other Cuban experiments in space, prepared in collaboration with the Ioffe Institute, included taking three-dimensional holographic picture sequences of the dissolution of a salt in a liquid.

After the decline of microelectronics activity due to the rise of large-scale integration, Cuban research in solid-state physics was reoriented toward optoelectronic devices, photovoltaic sensors, and new materials. The semiconductor production plant began to assemble equipment from imported chips in 1984 and produced some integrated circuits, although it never managed to work at the level intended. In 1985, the Institute of Materials and Reagents (figure 1), closely connected with the faculties of physics and chemistry, was created at UH to work on materials, chemicals, lasers, and optoelectronics, in support of certain areas of industry. A national program in electronics was created in 1986, and the "Front for Electronics"—a major effort comprising not only science and technology but also investments in industry—coordinated all the institutions

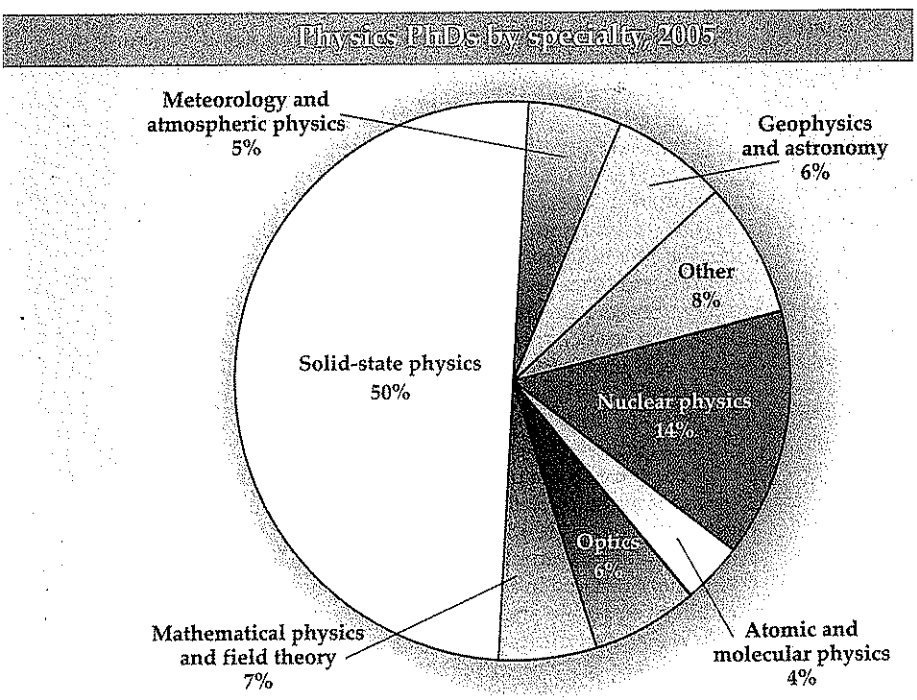
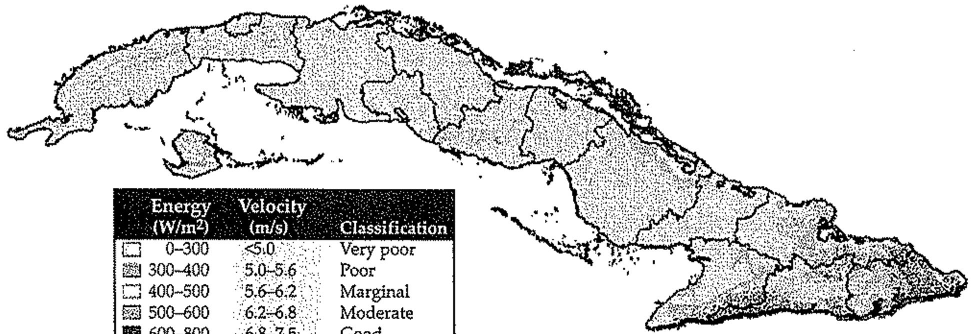


Figure 4. Of the 225 physicists with PhDs in Cuba, the majority are in solid-state physics and nuclear physics. The data were obtained from the National Commission of Scientific Degrees.



Energy (W/m^2)	Velocity (m/s)	Classification
0–300	<5.0	Very poor
300–400	5.0–5.6	Poor
400–500	5.6–6.2	Marginal
500–600	6.2–6.8	Moderate
600–800	6.8–7.5	Good
800–1000	7.5–8.2	Excellent
>1000	>8.2	Exceptional

Figure 5. Wind energy is a promising source of renewable energy. In collaboration with other national institutions, Cuba's Meteorology Institute recently finished this first edition of the Cuban wind map, based on 30 years' worth of direction and velocity data from 49 national meteorological stations.

connected with the national electronics industry, informatics, and industrial automation.

Producing a high-temperature superconductor at UH in 1987, just six months after the discovery of the phenomenon, was made possible by previous studies of ceramic compounds. A superconductivity laboratory was soon created at UH and its members have published tens of papers in international journals.

A research center on solar energy, devoted to research in energy saving, was created in 1982 in Santiago de Cuba, as an arm of the ACC. At Oriente University, activities were reoriented toward the nickel industry, and interesting work in nuclear magnetic resonance led to the creation of the Center of Medical Biophysics, an independent institute[4] that has designed and constructed several magnetic resonance imaging (MRI) facilities.

Another arm of the ACC—the Institute of Cybernetics, Mathematics, and Physics—hosts a theoretical physics group devoted to research in problems of quantum field theory, high-energy physics, and condensed matter and is supported with help from the International Centre for Theoretical Physics (ICTP) in Trieste, Italy. The group has organized four Caribbean workshops on quantum mechanics, particles, and fields, and has hosted a school on string theory.

By 1990 the physics programs at Havana and Eastern universities and at the ISCTN were averaging 50 graduates per year. The five-year curricula, strongly influenced by the Soviet system, were characterized by a solid theoretical and experimental foundation, and involved students in research from the first years of the program. A national network of higher institutes of pedagogy was preparing secondary-school physics teachers. And the Vocational Pre-University Institutes of Exact Sciences, located in all of Cuba's provinces, were providing an excellent source of young people well trained to study science and engineering at the universities. Some of the institutes' graduates participated in the national and international olympiads in physics[5] (see figure 2), chemistry, and mathematics. The 22nd International Physics Olympiad, held in Cuba in 1991, was the first physics olympiad organized by a Latin American country.

In the 1990 employment scene, a majority of physicists worked at the universities and the research 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 the equipment and supplies sufficed for work in experimental physics and in mathematical and theoretical physics. The most developed areas were solid-state physics, nuclear physics, optics and laser physics, medical physics, biophysics, and mathematical and theoretical physics. Physicists were also active in the interdisciplinary fields of meteorology, geophysics, astronomy, microelectronics, metallurgy, metrology, robotics, informatics, neuroscience, and molecular biology. Most PhDs were obtained in solid-state, materials, and nuclear physics.[6]

The Cuban Physical Society, created in 1978, had about 500 associates in 1990; from 1981 on, it was publishing the *Revista Cubana de Física* and holding a triennial symposium. International events were regularly organized in the country, and Cuban physicists collaborated with Soviet, European, and Latin American institutions. In addition, Cuba participated in physics-related international organizations, such as the Latin American Center for Physics, the Latin American Federation of Physical Societies, ICTP, the International Union of Pure and Applied Physics, the International Atomic Energy Agency, and the Intercosmos Program.

The past 15 years

With the collapse of the Soviet Union in 1991, the Cuban scientific community suffered a tremendous decrease in financial and material resources, and a dwindling of international exchange and scientific information. Electronics and nuclear energy, the national programs with the highest presence of physicists, were reduced, while priority shifted during the 1990s to sectors such as tourism, food, biotechnology, and medicine that were less related to physics. Many institutions, groups, and activities had to be redirected and reformed. The government's decision in 1998 to abandon the construction of the nuclear plant in Juraguá, which had been interrupted after the Soviet Union collapsed, prompted a redirection of research and teaching activities in nuclear science and technology.[7] Some research groups disappeared; others had to abandon or reduce active research. Staffing levels at research centers and universities were frozen, and the paralysis of industrial activities brought the growing presence of physicists in that sector to a halt. As a result, student enrollment in physics dropped. An estimated 200 physicists left the country, and an undetermined number sought better economic conditions in fields other than science. The average age of employed physicists grew; about half of present PhDs will have reached the age of retirement in 2010. Even with the economic restoration initiated in 1997, demand in physics research sectors has been feeble and mainly short term. Long-term programs have been difficult to develop, and physics has fallen behind as a priority of Cuban science.

This situation has obviously affected all activities in

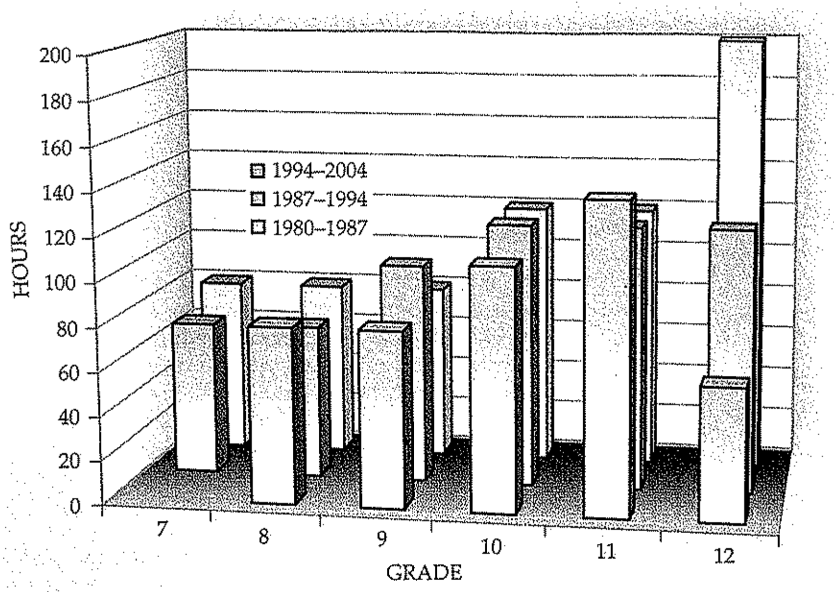


Figure 6. Annual hours of physics instruction in Cuba's secondary and pre-university schools. Physics instruction benefited from the creation of the Vocational Pre-University Institutes of Exact Sciences in 1979 and their later extension throughout the country in 1985. The institutes' objective is to assure a large and well-prepared pool of future specialists in science and technology. Recently, however, the total number of teaching hours has fallen; the effect of that reduction still needs to be evaluated.

physics. Still, having a critical mass of physicists with PhDs or lower-level university degrees and a stable science and higher-education system, Cuba has been able to withstand and overcome the difficulties.

Since the early 1990s, research into renewable energies and the environment has received additional attention in Cuba. Computing capacities have increased despite the shortage of powerful machines for scientific computing. The growth of informatics and communications has improved access to current technical and scientific information. This progress has induced a shift in several experimental activities toward simulation and modeling. Various teams have contributed to resolving the country's problems, designing and constructing medical and analytical equipment (see figure 3), performing technical and scientific services for industry, and generating new products. But the growth in computational activities has shifted the equilibrium between theoretical and experimental activities.

Cuban physicists had long benefited from access to the most advanced scientific institutions in socialist countries, but they now turned to the contacts previously established and maintained with other scientific milieus and institutions. Scientific exchange and collaboration shifted mainly toward Spain, Italy, Germany, and Latin American countries, especially Mexico and Brazil. Collaboration with ICTP has also been important.

In 2000, contacts between the Cuban Physical Society and the American Physical Society were reestablished. With the support of Nobel laureate Leon Lederman and APS director of international affairs Irving Lerch, exchange agreements between APS and the Cuban Physical Society were adopted[8] and two important meetings were organized in Havana: the International Workshop of Medical Physics in 2002, with 30 North American physicists participating, and the Inter-American Conference on Physics Education in 2003, with 34 North American teachers participating. Unfortunately, present American restrictions on academic exchange with Cuba have dramatically reduced scientific cooperation in physics.

Present and future

The new century began with stimulating signals for the recovery and advancement of Cuban physics. In keeping with the importance given to medicine in Cuba, medical physics is one of the branches with the greatest prospects. Investments of approximately $400 million in medical equipment are being made. At present, more than 75 physicists are working in clinical environments: 32 in nuclear medicine, 28 in radiotherapy, and the rest in diagnostic imaging and radiation protection. New equipment for radiotherapy and nuclear medicine will require at least another 20 physicists in those areas. Diagnostic imaging will be reinforced with the installation of eight new MRI facilities. An MSc degree program in medical physics at the Higher Institute of Technologies and Applied Sciences has started, with 25 students; an advanced degree program in radiation oncology is training specialists in that field; and a new degree program in health technology, offering specialization in medical radiophysics (equivalent to dosimetry), has 100 students registered.

More than 24 excimer laser systems for refractive surgery and other advanced optical instruments have been bought in an effort to provide ophthalmologic services to Cubans in all areas of the country. Those services are also being made available by Cubans in other parts of Latin America. Safe operation and maintenance of the equipment will create new jobs for physicists and engineers.

New instruments conceived and designed by teams led by Cuban physicists are continuing to be introduced in Cuba and abroad. A network of medical imaging systems, including MRI instruments, is being formed. Improvements are also under way for clinical-analysis and analytical-chemistry equipment, such as microfluorimeters and spectrophotometers for the early detection of congenital diseases and the diagnosis of hepatitis, AIDS, and other diseases. Medical instruments employing lasers for physiotherapy and laserpuncture will be incorporated in primary healthcare. New versions of automatic laser polarimeters are being developed for the sugar, pharmaceutical, and food industries and will also be included in chromatographic systems for biotechnology.

Condensed matter physics is still the field employing the largest number of Cuban physicists (see figure 4). A national program for scientific research and innovation on new and advanced materials, approved in 2003, gives priority to research in that field, with emphasis on nanotechnology and new materials.

In nuclear physics, radiation–matter interactions are being studied for the modification of solid materials. Cuba has become the 29th member of the ALICE high-energy physics project at CERN and is participating in its experimental and theoretical work.

Physicists have played an important role in establishing and developing meteorological services in Cuba. That sector is being strengthened with investments in modern equipment, which will, in turn, produce a new stimulus for physics. The field of renewable energies, in which physicists have always made significant contributions, is also expanding. A plan has been developed to install wind power stations in the near future. (Figure 5 shows a wind map of Cuba.)

During the past 40 years, physics education has been subject to systematic and intensive improvement in Cuba. Nevertheless, there has been a small reduction in the hours spent teaching physics in secondary schools (see figure 6), and a shortage of teachers has affected the quality of the education. To compensate for these shortcomings, widespread use of television classrooms and other modern teaching techniques are being introduced.

At the universities, the number of physics students is increasing slightly, the study of physics has been extended to the Central University, and a new program in physics engineering is expected soon. A general reconstruction of the UH building housing the EF and renovations of the equipment for the teaching labs are under way.

Compared with biotechnology and other branches of biomedical research, physics is only a small sector of Cuban science. Nevertheless, Cuban physicists are very active and their involvement in academic life and technical development, publications, prizes, scientific meetings, and popularization of science is relatively high. The celebration of the International Year of Physics in 2005 gave a new push and increased visibility to those efforts. Future progress will depend to a large extent on the success in bringing new generations of students to physics and applying the subject to the problems connected with Cuba's economic and social development.

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