PROFESSOR MIHAI GAVRILĂ AT HIS EIGHTIETH ANNIVERSARY

Professor Mihai Gavrilă has a privileged position in Romanian theoretical physics. Firstly, he has validated himself as an outstanding professor of quantum theory within the Department of Physics, at the University of Bucharest, where he has taught practically all classes of students between 1956 and 1974. Secondly, starting with his doctoral thesis, he has developed a remarkable research career in the field of theoretical atomic physics, extending over some fifty-five years (1955–2010) in Romania and abroad. His scientific results have been widely acknowledged and continued by his Romanian collaborators, as well as by the international atomic physics community. Last, but not least, he has been energizing many younger Romanian physicists by his example, his lectures, and his ideas. He can therefore be regarded as a true follower of Professor Şerban Ţiţeica whose close pupil he was. We give in the following some of his biographical and professional data.

1. ACADEMIC CAREER

Mihai Gavrilă was born in Cluj, on 10 October 1929. His parents were the medical doctor Ion Gavrilă (1898–1976), who became a distinguished professor at the Medical University of Cluj, and Florica Gavrilă, born Vişoiu (1903–2005), an accomplished professor of English at the same institution. For high school, he first went to *Liceul Gheorghe Lazăr* in Sibiu (1940–1945), during the war-time occupation of Northern Transylvania, and then to *Seminarul Pedagogic Universitar* of the University of Cluj (1946–1948).

In October 1948 he enrolled in the Department of Mathematics and Physics, at the University of Bucharest (denoted further as UB). This was against the wish of his family, which would have liked him to become a medical doctor, but finally gave in. His interest in physics originated in having had excellent teachers in physics and mathematics, and in having educated himself in the contemporary achievements of nuclear physics. Note also that 1948 was the year of the communist reform of higher education in Romania, intended to align education to the needs of the regime, which imposed a dramatic change on the subsequent evolution of events. After excellent studies in those difficult times, he graduated from the Physics Section of the Department in February 1953, majoring in

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radiotechnology. The latter choice was purposefully made by him in order to extend his knowledge of experimental physics, as he wanted to become a theorist anyway. He was particularly attracted by the theoretical physics lectures of Professor Şerban Ţiţeica. While still a student, from June 1951 to October 1953, he was given a position of research assistant in optics in the laboratory of Professor Eugen Bădărău. In November 1953, he achieved his goal of being awarded a PhD fellowship to work with Professor Şerban Ţiţeica as a supervisor. The subject of his thesis was the *Theory of Relativistic Photoeffect*. In his doctoral work, Mihai Gavrilă developed corrections to the well-known formula for the *K* shell derived by Fritz Sauter in 1931. His PhD thesis, defended in 1958, became the first Romanian *in-extenso* article to be published in the *Physical Review* [1], at a time when contacts with the West were prohibited. This work was continued by research on various aspects of the photoeffect and on other atomic inner-shell phenomena, as it will be shown in Section 2.

In September 1956 Mihai Gavrilă (whose name is hereafter abbreviated as MG) was appointed Assistant Professor in the Department of Physics of UB. This was the starting point of a distinguished academic career at UB, which extended through 1975. He became successively Associate Professor (1962) and Professor (1968). He started by teaching theory of black-body radiation, statistical mechanics, and kinetic theory (1956–1958).

However, in the interval 1957–1974 he taught primarily the general course on quantum mechanics. This one-year course was packed with information, at the international advanced level. MG developed his own approach to the subject, quite different from that of his mentor, Şerban Ţiţeica. Indeed, it was based on the wave aspect of quantum mechanics, rather than on correspondence-principle ideas. Started in an inductive manner, and then presented on an axiomatic basis, MG's influential lectures stressed the Copenhagen probabilistic interpretation which has always been defended by Şerban Ţiţeica. Moreover, he preferred to present general methods which, although more cumbersome to teach, were more rewarding in the end because the larger array of cases they could encompass. Considerable emphasis was laid on the fundamental principles of the theory. At the same time, numerous exercises and applications illustrating the principles gave practical mathematical tools even to the average student. MG's course on quantum mechanics became soon a benchmark in the curriculum of the Department of Physics. It also became a major hurdle for students to pass. This was underscored by the high standards he required for passing the exam, by testing in depth the knowledge of the student.

In the 1960s MG invested a lot of effort in the newly created specialization section in theoretical physics of the Department. A lasting success has been his one-year graduate course on group representations and their applications to physics (nonrelativistic quantum mechanics, atomic physics, relativistic quantum physics, particle symmetries), taught in the decade 1962–1972. He also gave beautiful lectures on advanced quantum theory (1971–1973). His students at the time were excellent. Moreover, he could rely on a group of dedicated teaching assistants (mentioned in chronological order): Viorica Florescu, Dan Horia Constantinescu, Mircea Ţugulea, Sorin Mărculescu, Doina Bunaciu, Tudor Marian, and Andrei Mezincescu.

In the meantime, MG's research interest switched from the relativistic inner-shell photoeffect to the photon scattering by atomic hydrogen. He was the first to apply to physical phenomena the recently discovered closed-form expressions of the nonrelativistic Coulomb Green's function (CGF). Indeed, he first employed the Hostler-Pratt expression of the CGF in configuration space [2] and then the Schwinger momentum-space integral representation [3] to study the Rayleigh scattering from the ground state of a hydrogen-like atom. For MG and his collaborators this research line has been quite rewarding over several decades starting with 1967, as shown in Section 2. In 1974 Professor Mihai Gavrilă has been elected as a corresponding member of the Romanian Academy.

At the same time, his research was stimulated by a number of visiting-scientist appointments abroad, at some prestigious scientific centers: Joint Institute for Nuclear Research (JINR) at Dubna (1964); Joint Institute for Laboratory Astrophysics (JILA) at Boulder, Colorado (1966); International Centre for Theoretical Physics (ICTP) of the International Atomic Energy Agency (IAEA) at Trieste (1967, 1968). In 1969 he was awarded a one-year JILA Visiting Fellowship. Finally, he had visiting appointments at the University of Pittsburgh (PITT), Pennsylvania, with Professor Richard H. Pratt in 1973 and 1974.

Meanwhile, at the beginning of the 1970s, the communist regime in Romania had tightened its grip on the country, trying to further isolate it from the West. Stricter rules were being applied in terms of communist indoctrination, scientific contacts, and travel. They were part and parcel of a strong trend of political discrimination in any institution and profession. Under the new circumstances, MG was particularly vulnerable due to his numerous international contacts. MG has never been a member of the Romanian Communist Party and had avoided all official appointments, for fear that these could eventually lead to such an affiliation. Besides, he felt that his opinion did not matter anymore. This led him to decide to leave the country and start all over again elsewhere (fall 1974).

In the transition period that followed he had visiting-professor appointments at the University of Trondheim, Norway (1974) and the Royal Institute of Technology (KTH), Stockholm (1975). He settled down at the FOM-Institute for Atomic and Molecular Physics (AMOLF) in Amsterdam (1975), where he became a group leader in theory. He worked uninterruptedly at AMOLF until 1992, and intermittently thereafter. At that time he moved to the Institute of Theoretical Atomic and Molecular Physics (ITAMP) at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, where he was appointed as a senior scientist.

During his stay at AMOLF the research interests of MG took a different direction: he began work in the area of laser-atom interactions, particularly in the superintense regime, i.e., intensities exceeding one atomic unit (*au*). This was done interactively with the experimental groups of Marnix van der Wiel and Harm-Geert Muller, international leaders in the area. This research was pursued together with a group of dedicated collaborators, leading to some remarkable discoveries. Details on this subject are given below, in Section 2. A large number of publications was produced. He presented them in some 43 invited talks at general conferences such as the International Conference on Atomic Physics (ICAP), the International Conference on the Physics of Electronic and Atomic Collisions (ICPEAC), and at topical ones like the International Conference on Multiphoton Processes (ICOMP), as well as at workshops and summer schools. The graduate students under his supervision finished with outstanding theses.

Beside his research, MG had a number of other professional activities worth mentioning. He was on the organizing/program committee of international conferences (ICAP, ICPEAC, ICOMP). He was member of the editorial board of the Physical Review A (1991–1993), and referee for more than 200 papers for the Physical Review A, Journal of Physics B and other journals. He has participated in numerous approved grants from the European Community (EC) and FOM Netherlands. The most notable of them was the EC grant on *Atoms in Superintense, Femtosecond Pulses*, of which he was the coordinator (1989–1994). This involved the collaboration of four experimental and theoretical labs from France, the Netherlands and Belgium, for the building of a superintense laser, at the *Laboratoire d'Optique Appliquée*, Palaiseau, France, and the development of the related theory. It was the most expensive grant the EC had funded until then (in present currency, about one million euros), and was accomplished successfully.

After the collapse of the communist regime in Romania, in December 1989, MG could return again to his native country (May 1990), after sixteen years of absence. Since then he has visited Romania about twice a year. In the twenty years after his return he has taken active interest in the development of physics in our country. He has participated in conferences and workshops, giving talks on various aspects of laser-atom interactions. The first one after his return, *Multiphoton processes in intense laser fields*, given at the Department of Physics, UB, on 8 May 1990, was a remarkable happening, the lecture hall being packed with local notabilities, professors and students. In the following years he has initiated successful collaborations with young Romanian physicists from the UB: Mircea Marinescu, Mihai Dondera, Ionel Sîmbotin, Mădălina Boca, and Marius Stroe. These collaborations have led them to successful publications and PhD theses on laser-atom interactions. At the same time, he has continued his decades-long collaboration with Professor Viorica Florescu. Besides he has helped scores of young Romanian graduates to doctoral fellowships in the Netherlands and USA.

2. RESEARCH IN PHYSICS

As already mentioned, the research of Professor Mihai Gavrilă was carried out in two different areas of atomic physics: atomic inner-shell radiative transitions and laser-atom interactions. In what follows we shall briefly describe the results he obtained with his collaborators.

2.1 ATOMIC INNER-SHELL RADIATIVE TRANSITIONS

The research by MG in this area includes the following: relativistic photoeffect of the inner atomic shells; development of the CGF method for two-photon transitions of a nonrelativistic electron in Coulomb field and applications; resonant Raman-Compton scattering and the infrared divergence; extreme-relativistic Rayleigh and Compton scattering by bound electrons; two-electron, one-photon transitions.

Collaborators along the years in this area have been (in chronological order): Dan H. Constantinescu (UB), Viorica Florescu (UB), Adrian Costescu (UB), Mircea N. Ţugulea (UB), Richard H. Pratt (PITT), Jørgen P. Hansen (University of Amsterdam), James McEnnan (PITT), Puspajit Mandal (AMOLF), and David J. Botto (PITT).

MG's research started in connection with his PhD thesis (1958) on the relativistic photoelectric effect of the *K* shell [1]. Corrections to the existing Sauter cross section were calculated using the second-order Born approximation, and a method was found for handling the specific divergences involved. Similar methods were applied to the calculation of the relativistic *L*-shell cross section. Years later MG returned to the *K*-shell photoeffect for the calculation of its QED radiative corrections [7], the last corrections to a major physical process that had not been worked out at that time.

Second-order transition matrix elements (nonrelativistic or relativistic) for Rayleigh, Raman, or Compton scattering, two-photon free-free transitions, etc., contain the Green's function for the atomic potential considered. MG has developed a method [3] to evaluate the matrix elements making use of Schwinger's integral representation for the CGF in momentum space, or a relativistic extension. This allows the calculation to be carried out analytically in terms of hypergeometric transcendentals of various kinds, which have known properties and that can easily be computed numerically. The method was applied to many cases by MG and collaborators. We mention in the following a few.

Thus, a simple dipole-approximation evaluation of elastic (Rayleigh) scattering of photons by the hydrogen atom in its ground state was given [3], which was considered an achievement at the time (1967). Next, a complete description of nonrelativistic Compton scattering from a bound *K*-shell electron followed [4]. This was extended to the case of the *L* shell, where unexpected physics was discovered [5,6], generating considerable theoretical and experimental interest. It was shown explicitly that the low-energy end of the scattered-photon spectrum exhibits an infrared divergence of the type predicted by QED [4,5,6]. Moreover, it was pointed out that a resonance appears in the scattered-photon spectrum of the L-shell Compton effect if the K_α line lies within it. These phenomena have been studied by four experimental groups led by: Isaac Freund (Bar-Ilan University, Ramat-Gan, Israel), 1976; Jean Pierre Briand (*Université Pierre et Marie Curie* – Paris VI), 1981–1990; Vincent Marchetti (Cornell University, Ithaca, New York), 1987–1990; P. P. Kane (Indian Institute of Technology, Bombay), 1987–1990.

More recently, the relativistic K-shell Compton scattering was evaluated in the limit of high photon energy, e.g., see [8]. The connection with the QED radiative corrections to the photoeffect was discussed.

2.2 LASER-ATOM INTERACTIONS

MG started studies in this area in 1976 at AMOLF, addressing multiphoton physics. As the laser fields at the time were weak in comparison to the atomic fields of interest, perturbation-theory methods could be used. Thus, in collaboration with Alfred Maquet and Valérie Véniard from the *Université Pierre et Marie Curie* – Paris VI, he studied two-photon continuum-continuum (*free-free*) transitions in the Coulomb field, in connection with ongoing experiments at AMOLF by Marnix van der Wiel and collaborators.

In later research, since 1984, MG and collaborators have addressed the issue of superintense laser-atom interactions, i.e., for fields in excess of $1au = 3.5 \times 10^{16}\text{W/cm}^2$. As the perturbation theory fails in this regime, new nonperturbative theoretical methods had to be developed and implemented numerically. This work has become increasingly relevant, in view of international efforts to develop facilities of extremely high intensities, extending towards VUV and X-ray frequencies. The collaborators of MG have been along the years (in chronological order): Jurek Z. Kamiński (Warsaw University), Marinus J. Offerhaus (AMOLF), Jacobus van de Ree (Eindhoven University of Technology), Marcellinus Pont (AMOLF), Niels R. Walet (AMOLF), Robert J. Vos (AMOLF), C.William McCurdy (Ohio State University), Wim van der Kaay (AMOLF), Harm-Geert Muller (AMOLF), Janine Shertzer (ITAMP), Mircea Marinescu (ITAMP and UB), Ernst van Duijn (AMOLF), Jack C. Wells (ITAMP), Ionel Sîmbotin (ITAMP and UB), Viorica Florescu (UB), Mădălina Boca (UB), and Marius Stroe (UB).

Achievements of MG and his group in the area of strong-field interactions have been: development of the *High-intensity, high-frequency Floquet theory* (HI-HFFT) and its applications; accurate large-scale computations within full Floquet theory in 3D and 1D; accurate numerical computations on atomic stabilization; development of the *Multi-state Floquet theory*. We mention here some highlights.

HI-HFFT was conceived originally as a novel approach within Floquet theory for the case of laser frequencies higher than the typical atomic binding frequencies, at all intensities [9, 13]. Subsequently, it has been shown that the theory could encompass also the case of high intensities at all laser frequencies [20]. Some fundamental, unexpected physics has been revealed. For example, in a field of linear polarization, the hydrogen atom exhibits *atomic dichotomy* [10, 11, 13]: namely, the spherically symmetric distribution of charge in its unperturbed ground state, while oscillating driven by the laser field, splits into two dichotomous charge lobes, as shown in Figure 1. In a field of circular polarization, the electric charge distribution takes the shape of a torus, with the C_∞ symmetry axis directed along the propagation vector and passing through the center of the unperturbed atom. Strong distortion was predicted also for two-electron atoms like H^- [14] and He.

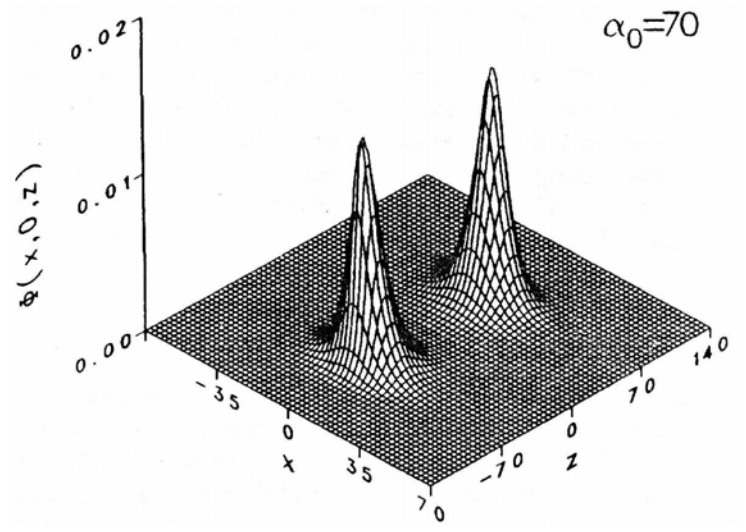

Fig. 1 – *Atomic dichotomy*. Representation of the HI-HFFT ware function $\Phi(x,0,z)$ of the ground state of atomic hydrogen in an intense laser field (frequency ω, intensity I) in the xz plane, where the z axis is directed along the field and the x axis is arbitrary. The relevant parameter in this regime is the classical oscillation amplitude $\alpha_0 = I^{1/2}\omega^{-2}$. All quantities are written in *au*.

HI-HFFT has led to exotic predictions on the possibility to create multiply charged negative ions of hydrogen which are relatively stable. It was shown that, in the presence of the field, a proton can bind more than two electrons [16]. As proven theoretically, such a process is not possible in the field-free case. New behavior is expected also for molecules. For instance, the field aligns the axis of the hydrogen molecular ion H_2^+ parallel to its (linear) polarization direction, and completely restructures its energy spectrum [15]. Furthemore, the appearance of new bound states induced by the field (*light-induced excited states*) was documented [17].

Related to the structural modifications of the atom in superintense fields are changes in ionization. Whereas at low intensities, the stronger the field acting on the atom, the more ionization is produced, at very high intensities the opposite counter-intuitive behavior sets in: the stronger the field, the lesser the ionization. This effect has been termed as *atomic stabilization* [12], see also [13]. The phenomenon has generated widespread interest: some 200 publications have been dedicated to the subject since its theoretical prediction in 1989, see [12], and several conferences have dealt predominantly with it: Super-Intense Laser-Atom Physics (SILAP) II (1991), SILAP III (1993), and ICOMP VI (1998), see [19]. Formal theoretical predictions have been confirmed by quite accurate numerical computations [18, 19]. Moreover, two state-of-the-art experiments were performed for its verification on Rydberg atoms (1993 and 1997) by H. G. Muller and his group at AMOLF, with positive outcome.

More recently, MG and his collaborators Mădălina Boca and Viorica Florescu have embarked on the study of relativistic electron dynamics in superintense fields. This is needed in view of the laser intensities currently available. A Pauli-type equation was extracted from the original Dirac equation, and the two were shown to be equivalent within the realm of laser-atom interactions.

A quick ISI-Web-of-Science inspection shows that, for the time being, the scientific papers by MG have collected about 2,200 citations found in about 1,120 articles. The Hirsch index is h =24, corresponding to an average number of about 30 citations per article. We have found out that among his most influential articles are some papers devoted to photon inner-shell interactions, like [1]: 59 citations, [3]: 121 citations, and [4]: 79+55 citations, and some other concerned with superintense laser-atom physics, such as [9]: 256 citations, [10]: 202 citations, [12]: 243 citations, and [19]: 67 citations.

To conclude, Mihai Gavrilă is one of the most valued professors of theoretical physics of the University of Bucharest, whose enlightening teaching and ideas have had long lasting effects on his students and collaborators. His remarkable scientific results have received widespread recognition in the atomic-physics community of our country and abroad. Moreover, in connection with the CGF method, he has created at the UB a school of theoretical atomic physics that has thrived for about three decades after his departure in 1975. Important results in this direction were obtained by Viorica Florescu, Adrian Costescu, Tudor Marian, and collaborators.

On the occasion of Professor Mihai Gavrilă's recent 80th birthday, we would like to express our personal appreciation, as well as that of our colleagues, for all his life-long activity, and for his efforts to promote physics in Romania. We wish him many more years of fruitful scientific and personal achievements, in good health and inner satisfaction. This special issue of the *Romanian Journal of Physics* is dedicated to his anniversary.

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