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Unveiling the World of Matter Waves

Quantum and Atom Optics forms the foundation of future technologies. Just as optics and electronics shaped todays technologies, today we can see how the quantum concepts start to influence and improve communication, sensing, navigation and computing devices all within a few decades. An upcoming branch of atom optics is the control of single atoms, potentially allowing solid state devices to be built atom by atom; some of which would be applicable in future quantum information processing devices. The application of atom optics techniques to nanofabrication might be a tremendous advance as the de Broglie wavelength of even cold atoms is much smaller than that of light.

Why diffract matter instead of light? Science continually attempts to find methods for measuring with higher and higher accuracy. What once could be accomplished using a ruler very roughly has evolved into detecting interference fringes of overlapping laser beams. This pushed the limits of measurement from the scale of what could be seen with the naked human eye to the scale of optical wavelengths. In order to go to smaller scales, one can use the wave nature of matter, which for practical applications is about at 10^{-10} meters. The light and matter diffraction is a cornerstone for the advent of interferometers, devices that use the wave nature of light and matter to detect small changes in distance.

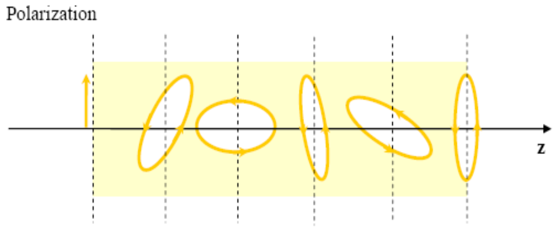
Some of the most important advances in recent years in atom-light interaction physics have been the storing and cooling of individual atoms and their interaction with light quanta. It was for the first time possible in the laboratory to generate systems that can be manipulated and measured at the level of single quanta atoms and photons.

Prof. Atom Muradyan developed his interest in atom-light interaction research field during his student years at Yerevan State University. This was the time when the field was establishing itself in Armenia with the efforts of Prof. Michael Ter-Mikaelyan and Prof. Vilik Harutyunyan.

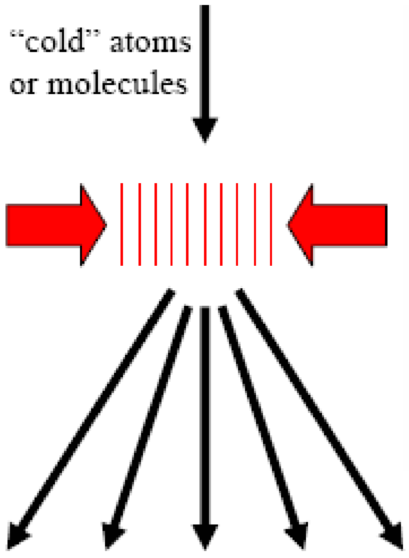
Prof. Muradyan graduated from Yerevan State University Physics Department in 1970. After working at Yerevan State University for two years as an Assistant, he moved in 1972 to the newly opened «Laser Physics» Research/Development/Production Scientific Center where he worked his way from a Researcher to become the Head of Laboratory and then the Head of Department. Following the theoretical footsteps of his supervisor Vilik Harutyunyan, Atom Muradyan became one of the most distinguished theoretical physicists of the field in Armenia.

In his early research, Muradyan studied the phenomena that formed the foundation of his later work. He worked methodically, made theoretical predictions, then helped to demonstrate experimentally the predicted results.

An example of important results that Muradyan and his collaborators developed during these years is the work where they showed that polarized ultrashort laser pulses induce dichroic-like optical anisotropy which rotates the plane of the probe beam polarization and transforms it into an elliptic one. This elliptic polarization has a beating eccentricity and axis directions, while the incident wave focus size has a jumping behavior depending on wave intensity and beam aperture.



He was among the researchers who showed for the first time that a superposition states can be created for the atomic center of mass motion through diffraction of atoms on a standing light wave (Kapitza-Dirac diffraction). Today this superposition state creation through the Kapitza Dirac diffraction lies in the basis of atom interferometry. Interference with atomic and molecular matter waves is a rich branch of atomic physics and quantum optics. It started with atom diffraction from crystal surfaces and the separated oscillatory fields technique used in atomic clocks. Atom interferometry is now reaching maturity as a powerful art with many applications in modern science. The basic tools for coherent atom optics include diffraction by nanostructures and laser light, three-grating interferometers, and double wells on atom chips using quantum gases. There are scientific advances resulted from the application of atom interferometers in fundamental quantum science, precision metrology, and atomic and molecular physics.



While working at «Laser Physics» Atom Muradyan had also a great input in experimental work carried out at the Center starting from generation of new frequencies in dense vapors and wave-front conjugation and finishing with light-induced optical anisotropy. These led to 4 USSR invention copyright licences.

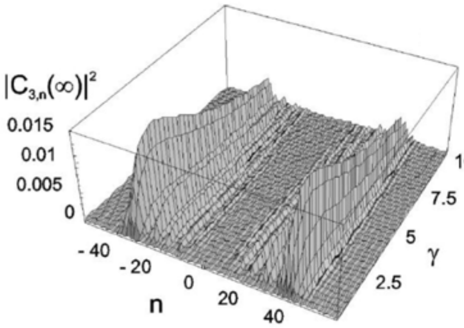
In 1995 Atom Muradyan accepted a Professorship at Yerevan State Univeristy Physics Department. His move led to the creation of Quantum Matter group at the Yerevan State University. Prof. Muradyan with his students and collaborators, continuing his research on fundamental questions, were able to report novel developments in the field.

Comparing the standing wave and counterpropagating wave characteristics they showed that Doppleron resonance for the counterpropagating waves dramatically differs from the standing wave case in the range of slow impact velocities and can be used to effectively cool the atomic gas. Since the physical reason for the above-mentioned differences is the existence of momentum conservation, it can be concluded that the modern cavity QED and the theory of measurement, being developed on the basis of quantized SW cavities, have in fact only dealt with the conservation of energy. The cavity QED and related problems for ring cavities, where the momentum conservation exists too and has to alter the state pattern in the 'atom + field' system, need to be determined. Moreover, the experimental confirmation just of the CPW case regularities, stationary or not, may be adopted as direct nonmediated evidence for the photon momentum to be quantized.

Coming from the fact that the interaction dynamics of an atomic wave packet with monochromatic laser radiation has qualitatively new aspects with respect to immovable (or initially having a definite momentum) atoms they discussed the evolution of energy level momentum distribution due to optical transition. Muradyan showed that during the interaction, the atom periodically gets large-scale changes in these momentum distributions. As a consequence, a portion of the atomic momentum of the states, corresponding to each internal energy level, gets large-scale changes too, much more than the momentum $\hbar k$ of an absorbed/emitted photon. For an important case, where the atom is initially in a superposition state prepared by coherent scattering on the resonant standing wave, the phenomenon for definite intervals of time can be presented as a transition from resonant Kapitza-Dirac splitting of atomic translational states into Stern-Gerlach-type splitting.

Considering interaction of a two-level atom with a monochromatic field of radiation possessing a series of equidistant momentum states they developed a theory for collapse and revival phenomenon in the atomic internal dynamics and suggested a scheme for its realization in common experimental environment. The reason for this effect is the generation of a non-equidistant family of Rabi oscillations, the different phase evolutions of which lead to such a temporal behaviour. The revival characteristic time is about momenta number times longer than the collapse characteristic time and they both are proportional to the coupling wave intensity and inversely proportional to the resonance detuning.

Muradyan has made several research collaborations and stays with abroad. Among these with Prof. Paul Berman from University of Michigan, with Prof. Thomas Bergeman from Stony Brook Univeristy, with Prof. Mark Kasevich from Stanford Univeristy and Prof. Klaus Molmer from Aarhus Univeristy. The collaboration with Paul Berman resulted in a series of articles on atom infermotrey where theory of an atom beam splitter is developed involving the interaction of standing-wave field pulses with atoms.



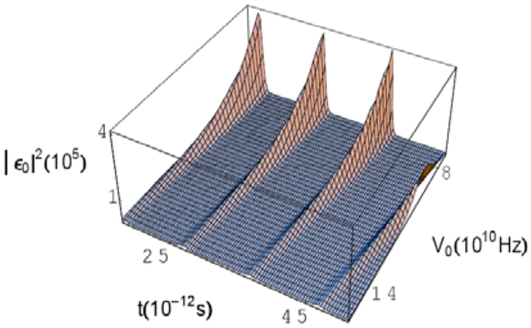
The suggested beam splitter consists of two interaction zones, both treated in the Raman-Nath approximation. Using this configuration one is able to create a large-angle beam splitter with a significant suppression of unwanted momentum components. This scheme is rather robust against fluctuations of system parameters.

Together with K. Mölmer they have extended the Raman-Nath approximation by including certain aspects of the kinetic energy in the diffraction process and proposed a phenomenological improvement to this solution which is based on physically motivated arguments. It was shown that this modiffication extends the validity regime of the parameter space of the analytical solution from the Raman-Nath into the channeling regime. Qualitatively the modiffication predicts asymmetry due to the Doppler effect in the diffraction pattern. The proposed analytical formula is found to be in good agreement even fairly deep in the channeling regime of strong and long interactions. Exploration of the channeling regime from the Bragg-formalism seems a promising avenue for attempts to provide good analytical expressions for atomic diffraction closer to the Bragg regime.

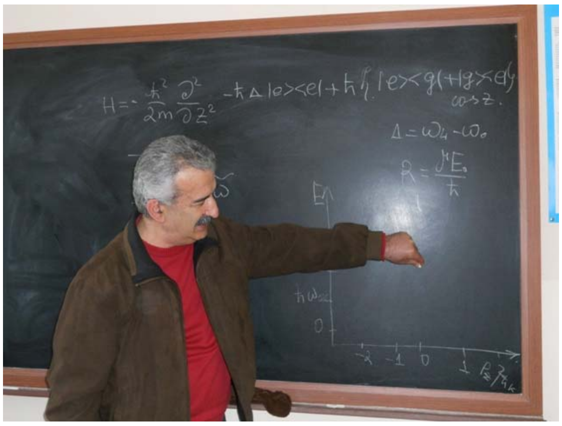
Recently, Atom Muradyan and coworkers suggested a new method for generating a regular train of ultrashort optical pulses in a prepared two-level medium.

Members of the YSU Quantum Matter group (from left to right): Artashes Movsisyan, Dr. Gevorg Muradyan, Prof. Atom Muradyan, Lilit Hovhannisyan and Mariam Hovhannisyan.

The train develops from incident monochromatic probe radiation traveling in a medium of atoms, which are in a quantum mechanical superposition of dressed internal states. In the frame of linear theory for the probe radiation, the energy of individual pulses is an exponentially growing function of atom density and of interaction cross section. Pulse repetition rate is determined by the pump field's generalized Rabi frequency and can be around 1 THz and greater. Also was shown that the terms, extra to the dipole approximation, endow the gas by a new property: nonsaturating dependence of refractive index on dressing monochromatic field intensity. Contribution of these nonsaturating terms can be compatible with the main dipole approximation term contribution in the wavelength region of about ten micrometers (in the range of CO_2 laser) or larger.



Atom Muradyan has recommended himself as a gifted administrator too. From 1993 to 1997 he headed the department of pre-earthquake signal detection and data analysis in the National Seismic Defence Center. From 1998 to 2002 he worked as vice-Director of the «Mashtots» Scientific-Engineering center, increasing the scientific research level at the Center. Today he is the head of the Methodical council of YSU Physics Department and during the last couple of years accomplished a huge work preparing the transition to a Credit system in the department according to the Bologna treaty.



Prof. Muradyan is the one responsible for inclusion in YSU Physics Department Bachelors and Masters Programme of such courses as «Random Motion of Particles», «Atoms in optical potentials», «Laser cooling of gases and Bose Einstein condensation» and «Quantum cloning». His textbook «Random motion of particles», published in 2006 was the first book on that questions in Armenian.

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