Shifman's Profile

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The most fundamental components of the universe are protons and neutrons. By 1970 it was clear that protons and neutrons are just two representatives of a huge family of hadrons, which include, among dozens of other particles, π, K, ρ, etc. At that time, the dynamical laws governing the hadronic family were a total mystery. This changed, overnight, in 1973 with the revolutionary discovery of *quantum chromodynamics* (QCD), the theory of hadrons. Experimental puzzles that had been accumulating for decades began unfolding one after another. This exciting time coincided with the beginning of Mikhail Shifman's research career.

According to QCD, hadrons are not elementary, rather they are complicated conglomerates composed of quarks and gluons. The gluons are responsible for the binding force between the quarks. This binding has a very special nature – the further apart the quarks are split, the stronger the binding potential, so that "isolated" quarks do not exit. This feature was named color confinement, a dynamical regime with no analogs in other bound systems that had been studied previously.

The impact of the gluon "medium" and color confinement on the quark degrees of freedom became the focus of Shifman's research for years to come. QCD opened new possibilities for the solution of long-standing mysteries. A dramatic issue was a huge enhancement of the decay $K_S \to \pi^+\pi^-$ over a similar $K^+ \to \pi^+\pi^0$ and analogous unexplained enhancements in a variety of the hyperon decays. Shifman (with Vainshtein and Zakharov) discovered a class of graphs (later dubbed *penguins*), shown to be responsible for this enhancement. This was one of the early triumphs of quantum chromodynamics. The penguin graphs proved to be instrumental in a wide range of phenomena – from CP nonconservation to rare heavy flavor decays.

At short distances ($< 10^{14}$ cm) quarks and gluons fully describe QCD dynamics. At larger distances ($\sim 10^{13}$ cm) these degrees of freedom become irrelevant because of the color confinement. The hadronic degrees of freedom take over. The transition occurs at strong coupling where familiar methods of dealing with field theory fail. The hope for understanding laws of the hadronic world lay with the development of new methods. Two such methods exist today, the inception of both can be traced back to 1978.

One of them, lattice QCD, is purely numerical. Space and time are discretized and are represented by a finite number of isolated points, each of which is endowed with a number of internal degrees of freedom. Then Monte Carlo simulations are performed. This method relies on powerful computers, and is very costly. Moreover, it is not transparent: human control is essentially lost.

Shifman, Vainshtein, and Zakharov chose another route. They observed that an intermediate domain of distances exists where, on the one hand, the hadrons are already well formed and, on the other hand, the gluon "medium" can be approximately described by a few average characteristics, the most important being the gluon and the quark condensates. If so, the spectral and other properties of the hadronic states can be approximately related to the condensate parameters. This route led to remarkable successes: basic regularities of the hadronic family were explained, as well as many fine details. The method goes under an awkward name of *QCD sum rules*. The original Shifman-Vainshtein-Zakharov publication on the QCD sum rules is one of the most cited papers in high-energy physics.

The condensate-based description of hadrons was further expanded in the 1990's, with new elements added and fresh findings incorporated. One such finding was a *heavy quark symmetry*. It reveals itself only in the heavy quark sector that, at that time, became the focus of experimental studies. One of the early works establishing the heavy quark symmetry was carried out by Shifman with Voloshin. It provided an impetus for the construction of the heavy quark mass expansion, which culminated at TPI in the 1990's, in a quantitative theory of the decays of c and b flavored hadrons.

The advent of QCD solved, at least at a conceptual level, all problems concerning the theory of hadrons. It brought a new one, however. CP conservation, which was believed to be a natural feature of the strong interaction, is lost in QCD due to a possible presence of the so-called θ term (an analog of quasimomentum in solid state physics). Weinberg and Wilczek suggested a new particle, axion, leading to an automatic "vacuum relaxation" and vanishing θ term. Their magnificent work was incompatible with data, however. Then, an invisible axion was suggested by Shifman and others — it preserves positive features of the original axion and, simultaneously, avoids unwanted contradictions. The invisible axion became a standard feature of the present-day theory.

Quantum chromodynamics and its applications in hadronic physics is one of Shifman's favorites, but not the only one. Another passion is *supersymmetry*. The beginnings of supersymmetry also date back to the 1970's. This is a very deep geometrical symmetry which connects the spin 1/2 fermions, the building blocks of matter (such as protons or electrons), with spin-0 or 1 bosons, which mediate the fundamental forces (e.g., photons or W bosons). It can be best characterized by the following quotation from Witten's recent article:

> "... One of the biggest adventures of all is the search for supersymmetry. Supersymmetry is the framework in which theoretical physicists have sought to answer some of the questions left open by the Standard Model of particle physics. Supersymmetry, if it holds in nature, is part of the quantum structure of space and time. In everyday life, we measure space and time by numbers, "It's now three oclock, the elevation is two hundred meters above see level, and so on. Numbers are classical concepts, known to humans since long before Quantum Mechanics was developed in the early twentieth century. The discovery of Quantum Mechanics changed our understanding of almost everything in physics, but our basic way of thinking about space and time has not yet been

> affected. Showing that nature is supersymmetric would change that, by revealing a quantum dimension of space and time, not measurable by ordinary numbers. ...Discovery of supersymmetry would be one of the real milestones in physics."

In the 1980's Shifman and Vainshtein obtained the first exact results in strongly-coupled supersymmetric theories – β functions and the gluino condensate. The methods they worked out were precursors to those used in establishing Seiberg's duality which led to the recent discovery of the string dualities.

Till recently, the Standard Model of particle physics and its supergeneralization was the only respectable paradigm of the modern theory. In recent years an alternative paradigm emerged, based on the idea that our four-dimensional habitat is nothing but a slice of a higher dimensional world (*living on a wall scenarios*). The matter with which our universe is built presents zero modes trapped on the surface of the wall. Imagine bugs crawling on the surface of a table unable to leave it. There is a critical energy needed to leave the wall and penetrate the bulk.

In 1982 when this conjecture was put forward (by Rubakov and Shaposhnikov) it was utterly premature and was ignored. The "living on a wall" idea was reintroduced in 1996 by Dvali and Shifman in connection with searches for novel mechanisms of supersymmetry breaking. This time it took off, and within two years became the dominant research topic in the community. Eventually it grew into four full-blown directions of research. Thousands of works have been published covering virtually all aspects of the "living on a wall" paradigm. Shifman is currently heavily involved in the use of 2+1 dimensional walls in four dimensions to study subtle properties of gauge theories at strong coupling.

Prof. Shifman was born in 1949 in Latvia. He got his Ph.D. from the Moscow Institute of Theoretical and Experimental Physics in 1976, where he worked till 1989. In 1990 Shifman moved to Minnesota to join the School of Physics and Astronomy and TPI. In 1997 he was elected as a Fellow of the American Physical Society. He received the *1999 J. J. Sakurai Prize for Theoretical Particle Physics* (with Vainshtein and Zakharov).