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# In memory of Semen Solomonovich Gershtein

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The outstanding Soviet and Russian theoretical physicist, academician of the Russian Academy of Sciences (RAS), Semen Solomonovich Gershtein, who made a fundamental contribution to atomic physics, particle physics, and astrophysics, passed away at the age of 93 on February 20, 2023.

Semen Solomonovich was born in Harbin (Manchuria) to a family of Soviet citizens. In 1936, he moved to Moscow together with his family. In 1937–1938, his parents were repressed (completely rehabilitated in 1955–1956). From the age of 8, Semen Solomonovich was brought up by his grandmother A I Mendelevich, who worked as a paramedic at a factory first-aid post.

In 1946, Semen Solomonovich finished secondary school with gold medal and entered the Physical Department of M V Lomonosov Moscow State University (MSU). In 1951, he graduated from the Physical Department of MSU and was assigned to work as a teacher at a secondary school in the village of Belousovo, Kaluga region, although the supervisor of his graduate work, Professor A A Vlasov, did his best for Gershtein to stay at the postgraduate school or to assign him to some scientific institution. S S Gershtein worked for three years in Belousovo. In spite of the workload at school (over 40 hours a week in two shifts), Semen Solomonovich managed to prepare in a little more than a year and pass very difficult exams in the legendary L D Landau theoretical minimum. He was the last person to take the exams personally from L D Landau. After Gershtein successfully passed the exams in the theoretical minimum, L D Landau recommended Semen Solomonovich to Ya B Zel'dovich, who was then engaged (along with on-site work on 'a special subject') in the theory of β decay. Together with Ya B Zel'dovich, S S Gershtein investigated the problem of the effect of strong interactions on the nucleon β decay constant. Along with the scalar (S) and tensor (T) versions of β decay, which were then thought of as experimentally established, the authors also considered the vector (V) and axial-vector (A) versions and arrived at the conclusion that the constant of the vector version of β decay is not renormalized by the strong nucleon-pion strong interaction. This was Semen Solomonovich's first published work.

Three years later, R Feynman and M Gell-Mann rediscovered S S Gershtein's and Ya B Zel'dovich's results, and the priority of the Soviet scientists in the discovery of an essentially new fundamental law of nature — the Conservation of Vector Current (CVC), which played an exclusively important role in the creation of the modern picture of the microworld — was recognized later. It was the CVC that compelled physicists to turn to the Yang–Mills theory, suggesting a description of interactions on the basis of gauge fields whose sources are conserved charges. This idea underlies not only the formulation of a unified theory of electroweak interactions (one of its basic points is the CVC) but also the creation of quantum chromodynamics.

Another mutual widely acknowledged result of the fruitful cooperation between S S Gershtein and Ya B Zel'dovich was setting in 1966 the upper limit on the total mass of all stable neutrinos from cosmological data. The obtained limit raised by several orders of magnitude the limits on the masses of muons and the later found $\tau$ neutrinos, obtained in laboratory experiments, and the very possibility of such estimates stimulated the joining of cosmology and elementary particle physics, which occurred in our time.

Semen Solomonovich Gershtein
(13.07.1929 – 20.02.2023)

In spring of 1955, on the initiative of L D Landau, Semen Solomonovich was accepted as a postgraduate student at the Institute for Physical Problems (IPP with P L Kapitza as director). After defending his candidate thesis in 1958, Semen Solomonovich worked for two years at the Leningrad Institute of Physics and Technology, where V N Gribov, Yu V Petrov, and others became his close friends.

At the beginning of 1960, on the invitation of A A Logunov and N N Bogoliubov, he moved to Dubna to work at the Laboratory of Theoretical Physics of the Joint Institute for Nuclear Research (JINR). The move was largely due to the fact that several experiments directly related to his studies were being prepared at the Laboratory of Nuclear Problems (LNP). Continuing the work begun by Andrei D Sakharov and Ya B Zel'dovich, Semen Solomonovich developed the

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theory of mesomolecular processes and nuclear reactions of hydrogen isotope synthesis induced by muons. He calculated the levels of mesomolecules and isotope exchange processes with allowance for corrections to the adiabatic approximation (in the first order with respect to the muon masses and nuclei) to find the main mechanism for the formation of mesomolecules with identical nuclei. At the same time, S S Gershtein pointed out the existence of the rotational-vibrational level with a low binding energy (below 7 eV) in the deuterium mesomolecule (ddμ) and suggested that resonance formation of mesomolecules in a given state could explain the considerable increase in the μ-catalysis rate in gaseous deuterium, discovered in experiments by V P Dzhelepov's team at LNP JINR. The specific mechanism of resonant formation of ddμ mesomolecules was found by S S Gershtein's postgraduate student E Vesman after Semen Solomonovich drew his attention to the fact that the binding energy, released during the formation of a mesomolecule $(dd\mu)^+$, could be transferred to the excitation of vibrations of an ordinary molecule, one of whose nuclei is a mesomolecular ion $(dd\mu)^+$. The result obtained initiated a search for a similar weakly bound level in the mesomolecule dtμ consisting of deuterium and tritium nuclei. Such a level was actually revealed by the group of physicists and mathematicians led by Semen Solomonovich's disciple, RAS Academician L I Ponomarev.

One of the most interesting mesoatomic processes considered by S S Gershtein was the fast transition between the levels of hyperfine mesoatomic structure due to the muon exchange upon mesoatom collision with the nucleus of the same hydrogen isotope. As was noticed by S S Gershtein and Ya B Zel'dovich, such a transition in hydrogen mesoatoms (pμ) increased by four times the probability of muon capture by a proton, which seamed to be very important for an experimental verification of the (V–A) version of weak interaction for muons. According to Semen Solomonovich's calculations, the transition rate of a pμ atom to a lower state turned out to be so high that the experiment could be performed in a gas without the production of mesomolecules that complicated the interpretation. This experiment was carried out in 2008, 50 years after it was proposed. A strong influence of mesoatom transition to a lower state of the hyperfine structure on μ-catalysis probability (the Gershtein–Wolfenstein effect) was also revealed. The predicted effect was observed in numerous experiments and for different isotope mixtures. S S Gershtein pointed out that the large cross section of muon transition from hydrogen isotopes to nuclei of other elements with charge $Z \geqslant 3$ was due to the intersection of molecular terms. The same mechanism proved to be valid in atomic physics and appears to be significant in the plasma of controlled thermonuclear fusion (CTF).

Mesomolecular processes and μ capture became the subject of Semen Solomonovich's doctoral thesis, the dissertation committee of which comprised academicians A D Sakharov, B M Pontecorvo, and A M Baldin.

In 1962, before the discovery of neutral currents and carrying out neutron experiments, S S Gershtein along with R A Eramzhan and Nguyen Van Hieu showed that the process of nuclear excitation under neutrino scattering could be used to search for neutral currents in the medium-energy range. This process was later the most convincing proof of solar neutrino oscillations and the validity of the Standard Solar Model.

In 1964, S S Gershtein went to work at the Institute for High Energy Physics (IHEP) and took an active part in the development of the research program at the accelerator under construction. Together with a group of experimentalists, he participated in the preparation of a program of neutrino experiments, including experiments with photoemulsions to search for short-lived particles.

Later, Semen Solomonovich, together with his students, performed a series of studies on the production of charmed quarks in neutrino experiments. Estimates of the hadronic cross section of the Υ meson and its radial exciters allowed the authors to determine the preferred charge of the b-quark.

In a series of studies carried out by S S Gershtein with a group of young scientists (A K Likhoded, V V Kiselev, and others), which followed the discovery of b-quark, calculations were made of the mass spectrum, lifetime, and production cross section of the $B_c(b\bar{c})$-meson and its excitations, later confirmed in experiments at the colliders FNAL (Fermilab) and the Large Hadron Collider (LHC). The latest measurements (2019) by the CMS, $LHC_b$, and ATLAS groups at the LHC showed radial excitations of the $B_c$ meson $B_c^*(2S)$. Examination of the production of hadrons consisting of heavy quarks allowed estimating the characteristics of another object — a baryon with two heavy quarks. The predictions of the theory were confirmed in 2018, when a baryon with two heavy quarks was observed for the first time.

In recent years, Semen Solomonovich considered some consequences of the field theory of gravitation developed by A A Logunov. In particular, in the work with A A Logunov, M A Mestvirishvili and N P Tkachenko, he obtained from the data on relic radiation anisotropy a limit on the possible graviton mass, which strengthened the previous result by three orders of magnitude.

S S Gershtein taught physics for many years: in 1958–1959 at the Leningrad Polytechnic Institute, in 1961–1962 at the Dubna branch of the Physics Department of MSU, and from 1963 he delivered general courses in theoretical physics at the Moscow Institute of Physics and Technology (MIPT). Among his former students are prominent scientists who remember him with gratitude. Semen Solomonovich is deservedly proud of the fact that four of his former pupils from the school in the village of Belousovo became doctors of sciences, and more than ten graduated from the branch of the Moscow Engineering Physics Institute (MEPhI) and worked at the Obninsk Institute of Physics and Power Engineering.

Semen Solomonovich did a great deal for the popularization of science. As a member of the editorial board of the encyclopedia *Physics of the microworld* and an editor-consultant of the *Bol'shaya Sovetskaya Entsiklopediya* (*BSE*) (the *Great Soviet Encyclopedia*), he wrote over a dozen articles for these editions. Till his last day, he had been member of the editorial boards of the journals *Priroda* (*Nature*), *Yadernaya Fizika* (*Nuclear Physics*), and *Teoreticheskaya i Matematicheskaya Fizika* (*Theoretical and Mathematical Physics*), as well as a member of the Bureau of the Division of Physical Sciences (DPS) RAS and expert commissions of DPS RAS.

Semen Solomonovich possessed a character notable for benevolence and, at the same time, intolerance to all manifestations of dishonesty in science and human relations. He always remained outside the clan approach to solving contentions questions and never tired of repeating that the principled position is the most correct.

Colleagues, disciples, and friends mourn deeply at the passing of Semen Solomonovich Gershtein, and the grateful memory of him will forever live in their hearts.

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