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SCIENTIFIC RESEARCH IN THE SOVIET UNION

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Abstract

I report on the scientific aspects of my US/USSR Interacademy Exchange Visit to the Soviet Union. My research was conducted at three different institutes: the Lebedev Physical Institute in Moscow, the Leningrad Nuclear Physics Institute in Gatchina, and the Yerevan Physics Institute in Soviet Armenia. I include relevant information about the Soviet educational system, salaries of Soviet physicists, work habits and research activities at the three institutes, and the relevance of that research to work going on in the United States.

This paper presented at the National Society of Black Physicists Conference, March 22-24, 1990 at Southern University, Baton Rouge, LA

I. Introduction

During the period December 28, 1988–June 25, 1989, I participated in the US/USSR Interacademy Exchange Program administered by the National Research Council. Under the terms of the program, I was accompanied by my wife, W. Estella Johnson, and two daughters, six year-old Sharifa Mtingwa and nine year-old Makazi Mtingwa. My itinerary is given in Appendix A.

At the Lebedev Physical Institute I was involved in theoretical investigations into the use of plasmas to accelerate electrons for possible use in the future generation of electron linear colliders. With Leonid Gorbunov, a distinguished plasma theoretician, I wrote a review article which summarizes the current state of affairs in the use of these plasma acceleration techniques. Our paper should be already published in the popular Soviet journal called *Knowledge*, which is written for the layman. This journal is published once per year in the form of a book and summarizes exciting new areas of scientific investigations.

At the Leningrad Nuclear Physics Institute, I studied the theory of CP (charge conjugation-parity) violation and possible tests of CP violation by studying the heavy B mesons. Jointly with Mark Strikman, I proposed a new scheme for generating the necessary number of B mesons for unlocking the mystery of CP violation (see *Phys. Rev. Lett.*, vol. 64, p. 1522, 1990).

At the Yerevan Physics Institute, I continued my work with Mark Strikman, who also visited Yerevan while I was there. Also, I continued my attempts to develop the theory of ferrites as possible media for wakefield acceleration experiments. In addition, I held many discussions with Yerevan physicists, as well as with other physicists who visited Yerevan, about their various programs of research involving new methods of accelerating charged particles.

In the next section, I describe the educational system which one must complete in order to become a scientist in the Soviet Union. I include information on Soviet scientific salaries. In Sections III–V, I describe work habits of Soviet physicists, their research activities, and my collaborations at the Lebedev Physical Institute, the Leningrad Nuclear Physics Institute, and the Yerevan Physics Institute, respectively. Finally, in Section VI, I comment on my research conclusions and the relevance of Soviet research activities to research ongoing in the United States. In Appendix A I give a full itinerary of my visits, and in Appendix B I give a listing of literature which I acquired.

II. The Soviet Educational System and Scientific Salaries

A chart of the Soviet educational system looks as follows:

Primary and Secondary School	*University (Undergraduate)*	*Aspirantura (Graduate)*	*Doctorate*
10 years	5-6 years	3-7 years	7-15 years
From ages 7 to 17	Finish about age 23	Finish at 26-30	Finish at 37-45

Upon completion of the Aspirantura (Graduate studies), the student is called a Candidate, unlike our designation of Doctor. In the Soviet Union Doctor has a more substantive meaning. About 10% of the candidates go on to achieve the title of Doctor, which is based upon years of excellent scholarly research. After achieving the title of Doctor, a few go on to attain the title of Professor, which is partly based upon supervising the research of about five Aspirants (Graduate students) enabling them to become Candidates.

The salary structure of Soviet scientists goes roughly as follows:

I. Aspirant (Graduate student working on thesis problem)- 100 Rubles/month

II. Mladshy Sotrudnik (Junior co-worker, not necessarily a candidate, so he/she may be without a Graduate degree)- 150-200 Rubles/month

III. Nauchny Sotrudnik (Scientific co-worker, should be a candidate) – 200-250 Rubles/month

IV. Starshy Sotrudnik (Senior co-worker)
Without title of Doctor–250-300 Rubles/month
With title of Doctor–350 Rubles/month

V. Vedushchy Sotrudnik (Outstanding co-worker)- 400-500 Rubles/month
Maximum paid only to Chiefs of Divisions.

VI. Glavny Sotrudnik (Head co-worker, usually Director of an Institute)–600 Rubles/month

To convert to U.S. dollars, the official exchange rate during my visit was 1.65 US dollars per ruble. The salaries seem very low but typical expenses are not very high. For example, an apartment can cost twenty-five rubles/month or less, although they are usually not available. The average wait for new couples to obtain their own apartments is about fifteen years. The rule is for young couples to live with their parents.

What can be said about Soviet scientists is that they work very hard under extremely adverse conditions and they are only minimally compensated for their efforts via salary, living conditions, medical care, etc.

III. The Lebedev Physical Institute

December 29,1988–February 27, 1989

At the Lebedev Physical Institute, my official hosts were Professors Andrei Kolomensky and Andrei Lebedev. But as for my research, I collaborated with three of their plasma theoretical physicists to whom Kolomensky and Lebedev introduced me. They were led by Leonid Gorbunov who received the State Prize in 1987 for his theory of the nonlinear dynamics of high frequency wave processes in fully ionized plasmas. He is also a Professor of Physics at Patrice Lumumba People's Friendship University. The other two were a Georgian physicist named Ramaz Ramazashvili and a Russian physicist named Viktor Kirsanov.

Every year a Soviet journal, *Knowledge*, is published in the form of a book and seeks to explain to the layman current areas of scientific research. Someone from that journal asked Gorbunov and me to write a mini-review of the plasma wakefield acceleration techniques currently underway in laboratories such as my own at Argonne National Laboratory. The issue containing our article should already be published.

In the plasma wakefield accelerator, a dense low energy bunch of electrons (called the driver) traverses a cold plasma leaving an electromagnetic field in its wake. A lower density second bunch of electrons (called the witness pulse) can then be accelerated by the driver's wakefield. Theoretically, the rate of acceleration for the second bunch can exceed 100 million electron volts (MeV) per meter; this is to be compared with the 15-17 MeV per meter which is obtainable at the Stanford Linear Accelerator Center (SLAC), the world's most powerful electron linear accelerator. In a slightly differently scheme preferred by Gorbunov, the wakefield can be generated by a single short intense laser pulse. Gorbunov has a long history of studyir^ the effects of high frequency electromagnetic waves propagating through plasmas.

In practically all theoretical discussions, the plasma density is assumed to be homogeneous. In our investigations at the Lebedev Institute, we considered the possibility of shaping the profile of the plasma density so as to maximize the energy obtainable by the witness electron pulse. Typically one wants to position the witness pulse on the crest of the electromagnetic wakefield wave profile. But as the witness pulse is accelerated, it begins to roll down the crest of the wave toward the decelerating phase. We found that by changing the plasma density profile, one can alter the wave profile so as to fix the witness pulse at the crest of the wakefield. Our results are contained in a paper to be published in one of the Lebedev Institute journals. The paper is entitled, *Increasing the Effectiveness of the Acceleration of Electrons by a Wave of Charge Density by Special Profiling of the Plasma Density.* The precise formula for how the plasma density should be shaped is given in the paper.

As an example, we considered the case of a single laser pulse of length 10^{-13} second generating a wake in a plasma with nominal density 10^{15} electrons per cubic centimeter. We found that for the case of uniform plasma density, the effective length over which a 50 MeV witness pulse can be accelerated is 300 centimeters, and it can attain an energy of 3 GeV. On the other hand, if the plasma density profile is shaped according to the prescription given in our paper, the effective length of acceleration is increased to 10 meters and the final energy of the witness pulse can be increased to 10 GeV.

While in Moscow, I gave three seminars on the new wakefield acceleration techniques: two at the Lebedev Institute and one at Patrice Lumumba People's Friendship University. One of my seminars at the Lebedev Institute seemed to stimulate Andrei Lebedev to want to perform similar experiments in their microtron, located about 20 kilometers outside Moscow. Their microtron accelerates 300 milliamperes of electrons to 24 MeV with a pulse train duration of 6 microseconds. Lebedev thinks that they can produce pulses short enough (roughly 6 millimeters) and with enough charge to perform useful wakefield experiments.

The normal working conditions for the physicists at the Lebedev Institute were rather difficult. As is the case throughout the Soviet Union, office space was extremely limited. Small offices, in which we would place only one person in the U.S., would contain three or four people. Also, office supplies were very limited. This included paper for performing calculations, xeroxing machines, etc. And as is the case in all Soviet research facilities, computers were not routinely available. Moreover, personal computers were a rarity. Unlike the situation in Leningrad (see below), the physicists at the Lebedev Institute worked a rather normal workday and usually worked in their offices rather than at home.

I felt that my collaboration with Gorbunov, Kirsanov, and Ramazashvili was a good one and could have significant impact if plasma wakefield acceleration is implemented in the future for high energy accelerators.

IV. The Leningrad Nuclear Physics Institute

February 28, 1989–May 5, 1989

At the Leningrad Nuclear Physics Institute (LNPI), my official host was Professor Alexei Anselm, Head of the Theory Department, and a theoretical high energy physicist whom I met several years ago during his visit to the Fermi National Accelerator Laboratory in Batavia, Illinois. I was a staff physicist there at the time.

The scientific activity of the LNPI covers the following areas:

- Elementary particle physics
- Nuclear and atomic physics
- Physics of condensed matter
- Molecular and radiation biophysics

All the internal activity at the Institute is grouped into divisions and laboratories according to scientific interest. The following is a current list of divisions and laboratories:

- High Energy Physics Division
- Neutron Research Division
- Theoretical Physics Division
- Molecular and Radiation Biophysics Division
- Condensed State Research Division
- Electronics and Automatization Division
- Radiation Detector Division
- Central Computer Division
- Mini- and Microcomputer Division

- Reactor Physics and Technology Division
- Accelerator Physics and Technology Laboratory
- Radiation Physics Laboratory
- Cryogenics and Superconduction Laboratory
- Informational Computing Systems Laboratory
- Laboratory of Holographic Information and Measuring Systems

The main research facilities of the LNPI are a 1 GeV protron synchrocyclotron, an 18 megawatt nuclear reactor WWR-M, and a 100 megawatt high flux nuclear reactor PIK (under construction).

The theoretical high energy physicists with whom I worked at LNPI rode the train to work only once per week. The other days of the week they would work at home or meet in small groups at their homes. In addition, they held a regular weekly seminar on Mondays in a building in Leningrad called the *House of Scientists.*

Traveling to work once per week was for two reasons. First and most importantly, there simply were not sufficient offices for the large number of physicists who worked at LNPI. So the same offices would be used by high energy theorists one day, by solid state theorists another day, and so forth. Secondly, the Institute was located in Gatchina, about 30 kilometers outside of Leningrad where practically all of the physicists lived. The commuting time from home to work was about 2 hours. So, about 4 hours were lost just in the commute to and from work. The high energy theorists typically went to Gatchina on Thursdays. Whenever scientists such as myself were visiting the institute, they arranged to have them ride to and from work in a special van. And there was usually room for some of the Leningrad scientists to ride as well. However, I stopped requesting the van after a while, because I enjoyed the rather lively political discussions on the train enroute to work, especially since I was in Leningrad during voting for the first-ever popularly elected

Syezd (Congress) which resulted in all Leningrad Communist Party members running for the Syezd being defeated.

Since the high energy theorists went to the office only one time per week, Thursdays usually involved a great deal of running around on bureaucratic errands and visits to the library to read journals and either drop off or pick up xeroxing. As for the xeroxing, it was not a simple matter as in the U.S. Typically, it took at least one week to have an article xeroxed; however, sometimes it would not be ready the following Thursday.

As in Moscow, the supply of office equipment was minimal, and paper was in short supply. I was told the reason being, that with the shortage of housing, top priority for wood was for construction. As a consequence, writing paper was not plentiful and used computer paper was often substituted for napkins in the cafeteria.

The big main-frame computers were pretty much reserved for the experimentalists. As a consequence, theoretical calculations tended to be slow and laborious, usually done by hand. This forced the theorists to specialize themselves to be able to do certain kinds of difficult calculations, so that if someone else needed something to be done, they knew who was best suited to do the calculation by hand.

While at LNPI, I studied CP violation theory with a young physicist named Nicolai Uraltsev. However, my main work was with Mark Strikman, who just had received his Doctorate the previous fall. Strikman and I wrote a paper entitled, *B Factory Via Conversion of 1 TeV Electron Beams into 1 TeV Photon Beams.* First, we derived formulae which describe the interaction of laser beams with electron beams. Then, specializing to the case of 1 TeV electron beams from the future generation of electron linear accelerators, we calculated the production rate of backscattered 1 TeV photons, and using these photons, we showed that it is possible to organize the photoproduction of beauty particles so as to measure 10^9 B meson pairs per year. This is the number that theorists haved argued is sufficient to study rare B meson decays and CP violation. At the conclusion of my Soviet trip I presented our results at the *Workshop on B-Factories and Related Physics Issues* held in Blois, France, June 26–July 1, 1989.

In other theoretical research at the Institute, A. Anselm and A. Johansen studied violations of the Adler-Bardeen theorem in multiloop order of perturbation theory resulting from photon-photon scattering. L. Frankfurt and M. Strikman studied short-range correlations in nuclei, involving light-cone quantum mechanics of the deuteron, structure of the single nucleon spectral function at large momenta, color screening effects in nuclear structure, and new options for studying microscopic nuclear structure at high energy facilities of the 1990's. Y. Dokshitzer, V. Khoze, and S. Troyan studied coherence phenomena and physics of QCD jets. Ya. Asimov, V. Khoze, and N. Uraltsev studied mixing and CP violation in the decays of B mesons. Yu. Petrov studied muon catalyzed fusion.

For the experimental program, there was a big effort to use their 1 GeV proton synchrotron to study the neutron electric dipole moment, K^+ lifetime, proton-neutron elastic scattering, proton-proton elastic scattering, and search for narrow dibaryon resonances. The Director of the Institute, Professor Alex Vorobyov, and co-workers were part of a big collaboration at the U.S. Fermi National Accelerator Laboratory to measure the Σ^- magnetic moment with FNAL Experiment E-715.

I gave one colloquium at LNPI in their beautiful auditorium in the main administration building. It was similar to the one I gave at the Lebedev Institute on new methods of accelerating charged particles using wakefields. Although no one there was involved in similar investigations, there was a great deal of interest in our results.

While in Leningrad, Anselm and his wife, Ludmila, were very gracious to me and my family and did everything they could to make our stay both profitable at work and enjoyable in general.

V. The Yerevan Physics Institute

May 6, 1989–June 1, 1989

At the Yerevan Physics Institute I continued to make progress on my research project with Mark Strikman of LNPI. Some of the physicists there were able to make useful input into that project. While I was in Yerevan, Strikman also visited there, so we had an opportunity to work together. Also, I continued to work out the theory of using ferrite materials to replace the plasma medium in the wakefield acceleration program.

However, most of my time at Yerevan was spent in discussions with the physicists there involved in both theoretical and experimental studies of new acceleration techniques, such as the plasma wakefield acceleration idea. As for plasmas, the physicists there were mainly interested in nonlinear effects. They want to reduce the charge density of their plasma to twice that of their driver charge density and thereby induce nonlinear plasma oscillations. The Director there, Professor A. Amatuni, thought that they may be two years from performing an experiment, although I got the feeling that it may be even longer.

Their reason for studying nonlinear effects is that these effects may allow the possibility to improve the transformer ratio (ratio of maximum acceleration of the witness pulse to the maximum deceleration inside the driver pulse). They had a theoretical team feverishly studying the nonlinear theory composed of A. Amatuni, S. Elbakyan, E. Lasiev, N. Nagorsky, M. Petrossyan, and E. Sekhpossyan.

For accelerators, Yerevan has a 2 GeV electron synchrotron, soon to be improved to 6 GeV, with a 50 MeV injection linac, soon to be upgraded to 75 MeV. Also, they are building a 150 MeV electron linac carrying 1.5 Amperes which could go up to 300 MeV carrying 0.3 Amperes. The new linac is predicted to be completed by 1993. One of these linacs could be used for their wakefield experiments.

High up on Mt. Aragats at 3200 meters, the Yerevan Physics Institute operates an installation called *Pion* to study cosmic ray physics. The Head of the installation is Professor E. Mamidjanyan. On May 8 they took my whole family on a tour of their facility.

There they hope to identify the hadronic composition and spectrum of cosmic radiation in the energy range 0.5-5 TeV. Also, they hope to investigate the interactions of pions, protons, and neutrons with target nuclei (eg. iron in the detector). They want to measure cross sections and compare with accelerator measurements and with theory, study quark-gluon structure, and determine the dependence of inelastic pion-nuclei and nucleon-nuclei cross sections on atomic number.

The typical life of the physicists at the Yerevan Physics Institute on the surface was more similar to that of physicists in the States than those in Leningrad and Moscow. One of the administrators there jokingly told me that in the Soviet Union, the further you are from Moscow, the easier life becomes. I found that offices were not as cramped in Yerevan as in Moscow and Leningrad. And the physicists seemed less stressed from their working conditions. On the other hand, almost every Armenian adult's life is consumed by the conflict between Armenia and Azerbaijan. Oftentimes, politics and the workplace were intermingled. It was not unusual for there to be political meetings in the middle of the workday on the lab site concerning the ethnic conflict with the Azerbaijanis. Tensions were extremely high while we were in Yerevan. During one week, public demonstrations were held every night in the center of town with some 200,000 to half a million people participating, although no mention was made of it on the evening news program, *Vremya.*

When word spread that I, as a representative of my Argonne group, was in Yerevan, several physicists from other cities came to hold discussions with me. Quite a few non-Yerevan physicists attended the colloquium which I gave in their main lecture hall. Since my group's work was rather well-known, they mostly wanted to get my impressions of their investigations.

My stay in Yerevan was very productive in terms of my research, learning about their programs and discussing my Argonne group's activities.

VI. Discussion and Conclusions

My research collaborations proved to be very successful during my Soviet visit. In Moscow at the Lebedev Institute, we were able to greatly optimize the acceleration of electrons in the plasma wakefield acceleration scheme. As explained above, this involves fixing the witness electron pulse at the maximum acceleration phase so as to avoid phase slippage to the decelerating phase. This is accomplished by shaping the plasma charge density profile according to the prescription contained in our paper as cited in Section III. Also, I had the rare opportunity to co-author a review paper for the popular journal, *Knowledge*, which describes the current interest and investigations into new methods of accelerating charged particles in the plasma wakefield acceleration scheme.

At LNPI in Gatchina, Mark Strikman and I succeeded in describing a scheme which could lead to the production and detection of 10^9 B mesons pairs per year, which is the number theorists believe is sufficient to study rare B meson decays and CP violation. Unlike other B meson factory ideas, our scheme produces so many B mesons that our main goal was to limit the number the detector has to process.

Finally, at Yerevan I continued my attempts to understand how ferrite materials can be used to replace plasmas as the medium which produces wakefields for charged particle acceleration. Also, I continued my work on the B meson factory with Mark Strikman.

Toward the end of my Soviet visit, I returned to both Leningrad and Moscow to finalize papers with my collaborators before departing for the B meson workshop in Blois, France. Also, I was required to leave the Soviet Union from Moscow.

In general I found that the high energy physics research programs in the Soviet Union were complementary to ours in the U.S. However, it is clear that their experimental high energy and accelerator physics programs are far below par when compared with those in the West. The physicists there complain of the long length of time needed to acquire funding to build equipment and the fact that they have to actually build so much from scratch themselves. This is unlike the situation in the West where so much of the major components are contracted out to private companies.

In theoretical physics, the Soviets fare much better. However, the lack of mainframe computer facilities and personal computers makes life very difficult for them. As a consequence, they play essentially no role in certain areas of physics research, for example computational lattice gauge theory.

However, despite all of their difficulties, the Soviet physicists are highly motivated and quite productive.

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APPENDIX A

Itinerary of My Soviet Exchange

- December 29, 1988–February 27, 1989

  P.N. Lebedev Physical Institute

  Leninsky Prospeckt 53

  Moscow

- February 28, 1989–May 5, 1989

  Leningrad Nuclear Physics Institute

  Gatchina

  Leningrad District

- May 6, 1989–June 1, 1989

  Yerevan Physics Institute

  Soviet Armenia

- June 2, 1989–June 14, 1989

  Leningrad Nuclear Physics Institute

  Gatchina

- June 15, 1989–June 25, 1989

  Lebedev Physical Institute

  Moscow

APPENDIX B

Literature Acquired

1. A. Amatuni, S. Elbakyan, and E. Sekhpossyan, *Nonlinear Effects in Plasma Wakefield Acceleration*, Yerevan Physics Institute Preprint No. YPI-935(86), 1986.

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3. A. Amatuni, E. Sekhpossyan, and S. Elbakyan, *Excitation of Strong Longitudinal Waves in Plasmas by Electron Bunches*, Physics of Plasmas (Short Reports), **12**(9), p. 1145, 1986.

4. A. Amatuni, M. Magomedov, E. Sekhpossyan,and S. Elbakyan, *Excitation of Nonlinear Stationary Waves in Plasmas by Electron Bunches*, Physics of Plasmas, **5**(1), p. 85, 1979.

5. A. Anselm and A. Johansen, *Radiative Corrections to the Axial Anomaly*, Letters JETP, **49**(4), p. 185, 1988.

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7. Y. Dokshitzer, V. Khoze, and S. Troyan, *Coherence and Physics of QCD Jets*, DESY Preprint No. 88-093, 1988.

8. L. Gorbunov, *Accelerators of the 21st Century? Laser Methods of Accelerating Particles in Plasmas*, **Nature**, May, 1988.

9. L. Gorbunov and S. Mtingwa, *Search for New Methods for Accelerating Charged Particles* (tentative title), to be published in **Knowledge**, Fall, 1989.

10. L. Gorbunov and C. Guttierrez, *Generation of Electrostatic Fields under the Passage of High Frequency Electromagnetic Waves through a Plasma*, Lebedev Institute Preprint No. 269, 1987.

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12. L. Gorbunov and V. Kirsanov, *Excitation of Plasma Waves by an Electromagnetic Wave Packet*, Sov. Phys. JETP, **66**(2), p. 290, 1987.

13. L. Gorbunov, V. Kirsanov, and R. Ramazashvili, *Theory of the Excitation of Langmuir Waves in the Plasma Beatwave Accelerator*, Short Physics Reports, Lebedev Institute **3**, p. 33, 1989.

14. L. Gorbunov and L. Anosova, *On Charge Neutralization of an Electron Bunch in a Plasma*, Journal of Technical Phys. **47**(6), p. 1150, 1977.

15. L. Gorbunov, V. Kirsanov, S. Mtingwa, and R. Ramazashvili, *Increasing the Effectiveness of the Acceleration of Electrons by a Wave of Charge Density by Special Profiling of the Plasma Density*, soon to be published in the Lebedev Institute Journal, Fall, 1989.

16. A. Kolomensky and I. Pakhomov, *Free Electron Laser on the Basis of a Modulated Axial Magnetic Field*, Short Physics Correspondences of the USSR Academy of Sciences, **8**(41), 1985.

17. A. Kolomensky and I. Pakhomov, *Collective Effects under Induced Radiation of an Electron Bunch in an Undulator with an Axial Magnetic Field*, Plasma Physics, **10**, p. 1275, 1984.

18. S. Mtingwa and M. Strikman, *B Factory via Conversion of 1 TeV Electron Beams into 1 TeV Photon Beams*, Argonne National Laboratory Preprint No. ANL-HEP-CP-89-96, 1989.