Laser research

Exchange visits have given us a good view of Soviet work on laser fusion, nonlinear optics, laser spectroscopy, isotope separation and the development of new lasers—and enhanced the prospects for further cooperation.

H. Richard Leuchtag

An impressive amount of research is carried out in the Soviet Union in the areas of laser physics and quantum electronics. PHYSICS TODAY asked a number of leading US physicists who have worked closely with the Soviets in these fields to give us their impressions of this work. They are Michael Feld, an associate professor of physics at MIT; Aram Mooradian, the leader, and Paul Kelley, the associate leader of the Quantum Electronics Group at the MIT Lincoln Laboratory; Keith Boyer, division leader for laser fusion at Los Alamos Scientific Laboratory, and Ali Javan, a professor of physics at MIT and an inventor of the helium-neon laser.

Soviet research

The scope of laser research in the U.S.S.R. encompasses a broad range. Some of the topics to be discussed in this article include: laser-induced thermonuclear reactions, nonlinear optics, laser spectroscopy, isotope separation with lasers and the development of various types of lasers including high-power lasers and short-wavelength lasers. Soviet scientists have also made substantial contributions in the areas of semiconductor lasers, chemical lasers and the development of lasers based on luminescence of crystals and glasses. Let us begin with some general impressions of laser research in the Soviet Union from the viewpoints of the visiting US physicists.

H. Richard Leuchtag is associate editor of PHYSICS TODAY.

Laser research is carried out at a number of centers, including the Lebedev Institute in Moscow, which is the Physical Institute of the Academy of Science; the Spectroscopy Institute of the Academy of Sciences; the Kurchatov Institute of Nuclear Physics (the Soviet AEC), which is active in some aspects of laser research, and the Institute of the Physics of Semiconductors and the Institute of Automation and Electrometry, both at Akademgorodok, the science city near Novosibirsk. Moscow University is also very active in laser research as are the Physics Institute of the Byelorussian Academy of Sciences at Minsk and the Physical Research Institute at Ashtarak, Armenia. Other centers of laser work are the Zuev Institute of Atmospheric Optics, the Ioffe Physicotechnical Institute, the Vavilov Optical Institute in Leningrad and the Gor'kii Radiophysical Research Institute.

Within the Lebedev Institute are two enormous laboratories: Academician N. G. Basov's Laboratory of Quantum Radiophysics, with a 400-member staff, and Academician A. M. Prokhorov's Oscillation Laboratory, with a staff of over 300 members. Laser physics is given considerable emphasis in the Soviet Union and Basov and Prokhorov, who shared the Nobel Prize with Charles Townes in 1964, have a great deal of authority and influence; Basov is also the director of the Lebedev Institute and Prokhorov is also the director of the Physics and Astronomy Department of the Soviet Academy of Sciences, which includes tens of research institutes in the U.S.S.R.

Javan told PHYSICS TODAY that Basov and Prokhorov "run the show" in establishing the direction and priorities of Soviet laser work. While the Soviets have at times initiated work in emerging areas, Javan finds that the main thrust eventually comes from the US. As an example he cites some very interesting observations Basov and his colleagues made on liquid xenon, but which they did not pursue vigorously; now much of the original work in this area is emerging from the US, he says. On the other hand, Javan feels that the Soviet work in fundamental areas is particularly distinguished. Their motive for undertaking an investigation is often not connected with any specific practical application or may be based on what is only a remote possibility—a daring approach.

Mooradian and Kelley commented on the heavy emphasis on and traditional strength in theory, but noted that the experimental wing of Soviet science, now hampered by a lack of facilities, is growing at a very rapid pace. They pointed out an interesting anomaly in Soviet labs: While such sophisticated items as powerful laser systems are often relatively easy to obtain, the choice of everyday equipment items such as oscilloscopes, minicomputers and optical components is much more limited than in the US.

Laser fusion

Boyer and Feld point to the field of laser-induced thermonuclear reactions as an especially active area. Basov initiated research in this field when he pointed out, as early as 1961, that heat-

Nikolai Basov, director of the P. N. Lebedev Institute of the Soviet Academy of Science, also heads the Laboratory of Quantum Radiophysics, which has a staff of some 400 members.

ing by an intense pulse of laser radiation could be used to trigger a thermonuclear microexplosion. His Laboratory of Quantum Radiophysics has been one of the world leaders in this area. The early work there was directed towards developing high-power pulsed laser oscillators and amplifiers, including q-switched ruby and neodymium-glass cascade amplifiers. This work led to the discovery of several new effects, such as propagation of pulses in a nonlinear amplifier in which the pulse peak travels at a velocity exceeding that of light because of the preferential amplification of the leading edge and the phenomenon of nonresonant feedback, and to the study of the interaction of high-power nanosecond laser pulses with the surface of a target. In 1968 Basov and his colleagues reported the first observation of neutrons emitted from a hot laser plasma.

The US has also been active in this field since the early 1960's although the work was initially classified. Laser fusion is now being developed intensively in several countries in the hope of devising a successful power-generating system. The basic problem is to obtain a significant energy gain with minimum incident laser energy and with the least demands on the quality of the laser radiation. Around 1968 the awareness developed in several laboratories that a sustained laser-fusion reaction could be achieved more easily by compressing the plasma, which would lead to an enhanced output of thermonuclear energy.

In the compression approach a deuterium–tritium pellet of the order of 1 mm in diameter is irradiated isotropically by the laser pulse. As the surface of the pellet becomes hot and vaporizes, the back pressure compresses and heats the central portion. It should be possible to obtain pressures of tens of millions of atmospheres, leading to compression by a factor of hundreds or thousands. Such an increase in density would lead to an enormous increase in the rate of thermonuclear burning, and under appropriate conditions most of the pellet would burn during the very short time of compression.

The first compression experiment was carried out in the Basov laboratory in 1970. In these experiments a 9-beam neodymium-glass laser was used to irradiate a spherical target of deuterated polyethylene. The laser delivered energies of the order of kilojoules for durations of several nanoseconds. In these pioneering studies, Basov, O. N. Krokhin and their co-workers achieved a 30-fold compression accompanied by a flux of the order of 10^7 neutrons per pulse from the D–D fusion reaction.

Two approaches towards maximizing the compression are the shaping of the laser pulses and the use of "hollow" targets—actually alternating layers of materials of high and low Z. The emphasis in the Soviet Union is on the latter approach. Mathematical modelling calculations at the Lebedev and at the Institute of Applied Mathematics by Academician A. N. Tikhonov, the director, and A. A. Samarskiy have led to target structures in which thermonuclear gains of up to 1000 are predicted to be attainable with a laser pulse of 10^6 joules. This approach makes shaping of the laser pulse unnecessary and enables pulses as long as tens of nanoseconds to be used with targets several millimeters in diameter. This in turn greatly reduces the difficulty with self-focussing of the laser radiation within the target. The Lebedev Institute is presently constructing a 15-kilojoule neodymium glass laser with a pulse duration of 1 to 30 nanoseconds.

In Prokhorov's Oscillation Laboratory, fundamental studies of the interaction of pulses of intense laser radiation with a dense high-temperature plasma have been carried out for many years. This laboratory initiated studies of x radiation and temperature of a laser-induced spark. Special attention is devoted to nonlinear processes, such as inverse stimulated Compton scattering, that limit the amount of laser energy the plasma can absorb.

The Soviets have developed several technological innovations in laser plasma diagnostics on extremely short time scales, including streak and x-ray cameras with resolutions of a few picoseconds. This technology has been used to study instabilities of dense laser plasmas in the x-ray region.

The Oscillation Laboratory and the Kurchatov Institute, headed by Academician E. P. Velikhov, are collaborating to develop a 32-beam laser capable of producing 10-kJ pulses of 0.1–10 nsec duration. the device, which uses neodymium-glass slab amplifiers, is expected to become operational about 1977.

Nonlinear optics

The attendance of some 600 Soviet scientists at a recent all-Union conference on nonlinear optics illustrates the great interest in this field in the U.S.S.R., Mooradian and Kelley pointed out. In comparison, there are only about 100 physicists working in this area in the US.

Moscow State University in the Lenin Hills is the most active center of nonlinear optics in the Soviet Union, according to Feld. Academician R. V. Khokhlov, rector of the university and head of the U.S.S.R. Scientific School in Nonlinear Optics, has been active in this area even before the development of lasers. After the advent of lasers, Khokhlov and S. A. Akhmanov jointly began a set of studies in laser nonlinear optics. One of their early achievements was the development of a mathematical formalism for treating nonstationary phenomena in nonlinear media, a work that was ultimately published in their book *Problems of Nonlinear Optics*, perhaps the first book on laser nonlinear optics.

On the experimental side, parametric oscillators were developed at Moscow State University in the mid-1960's, more or less simultaneously with similar work at Bell Labs. L. A. Kulevsky recently has developed a 10-kW cadmium-selenide parametric oscillator pumped by a CdF_2:Dy^{2+} laser at 2.4 microns at the Lebedev Institute; the device is tunable over a wide range, 2.8–3.8 microns and 8–14 microns.

With the Soviets' traditional strength in theory, there is an interesting difference in the way theory and experiment interact in the two countries: While Soviet theorists seek to predict new phenomena, American theorists are more often concerned with finding explanations for known experimental results. Thus US experimentalists have on occasion discovered a phenomenon only to learn that a Soviet theoretical paper had already predicted it—if only qualitatively.

An example of this was the discovery of the self-focussing of a pulsed beam of radiation. If a laser beam is strong enough, it alters the refractive index of the solid or liquid medium in a profile over the cross section of the beam. This effect was discussed in a 1962 paper by G. A. Askar'yan of the Lebedev Institute. Later, in studying anomalies in stimulated Raman scattering, Townes and his colleagues at MIT concluded independently that the unusually high laser intensities found could be explained by self-focussing and a related process called "self-trapping." N. F. Pilipetskiy and A. R. Rustamov observed this phenomenon experimentally at Moscow University, as did Nicolaas Bloembergen and Pierre Lallemand at Harvard. With cw beams in gases, heating by the beam can cause the opposite effect, defocussing. This phenomenon, also known as thermal blooming, was predicted by A. C. Litvak of the Gor'kii Radiophysical Research Institute and observed experimentally at Bell Labs.

Both the Moscow University group and V. I. Talanov and V. I. Bespalov at Gorkii have studied nonstationary self-focussing and the breakup of an intense beam of radiation into small filaments. These features have been extremely important in understanding the growth and propagation of powerful ultrashort pulses in neodymium-glass laser amplifiers. At the Lebedev Institute Prokhorov and V. N. Lugovoy showed that self-focussing may occur in multiple filaments and that, under certain conditions, a moving focus may arise, the trajectory of which resembles a nonlinear waveguide.

Alexander Prokhorov (right), who shared the 1964 Nobel Prize in physics with Basov and Charles Townes, is head of the Oscillation Laboratory of the Lebedev Institute. He and his coworkers are discussing joint research with M. L. Ter-Michaelyan (far left), director, and other members of the Physical Research Institute of the Armenian Academy of Science in Yerevan.

Laser spectroscopy

Soviet scientists have been quite active in the field of laser spectroscopy, Feld notes. In 1965 Basov and V. S. Letokhov, then his graduate student, explored the possibility of obtaining extremely narrow resonances within the Doppler profile of an atomic beam interacting with a monochromatic light wave. In present terminology their method can be described as a Lamb dip in oppositely propagating, spatially separated beams. The possibility of observing the Lamb dip in an absorbing rather than an amplifying gas was first suggested in the Soviet Union in 1967 by Letokhov, who proposed observing saturation resonances in the output of a 3.39-micron He–Ne laser with saturable methane absorber inside the laser resonator. V. P. Chebotaev and his collaborators at the Institute of the Physics of Semiconductors discovered this method independently and demonstrated the effect with a neon absorber in the resonator of a 6328-Å He–Ne laser. In the US, similar results were reported at about the same time by Paul Lee and M. L. Skolnick of the Perkin–Elmer Corporation. (Of course, many major contributions by scientists in the US, France, Japan and other countries are here—as elsewhere in this article—omitted.)

In an important set of experiments, Letokhov and O. N. Kompanets studied narrow resonances in polyatomic molecules with a 10-micron CO_2 laser. They investigated the depletion of a narrow portion of the velocity distribution of a Doppler-broadened transition, induced by an intense light wave, with a weak monochromatic probe field propagating in the opposite direction. These experiments began at the Lebedev Institute and are continuing at the Institute of Spectroscopy, where Letokhov is deputy director. This facility, headed by S. L. Mandel'shtam, is a research institute of the Soviet Academy of Sciences devoted entirely to spectroscopic studies.

In the OsO_4 molecule numerous effects, such as quadrupole splitting in vibrational–rotational transitions, have been observed. This group is now interested in increasing the precision with which the laser frequency can be locked into a narrow molecular resonance. An eventual aim is to search for a frequency splitting in the transitions of left- and right-handed molecules due to parity violation in the weak interaction, a possibility first suggested by Letokhov.

Over the past ten years Chebotaev's laboratory has specialized in developing techniques of high-resolution laser saturation spectroscopy and applying them to problems such as narrow resonances in three-level atomic systems.

In 1970 Chebotaev pointed out that the broadening due to the Doppler effect could be eliminated in two-photon absorption when the photons enter in opposite directions.

Another area of interest has been stabilization of the 3.39-micron He–Ne laser on the narrow absorption resonance in methane. Their values for long-term frequency stability, $1{:}10^{14}$, and frequency reproducibility, $1{:}10^{13}$, are the most precise results obtained to date. Another interesting observation is the anomalously small pressure-broadening and frequency-shift coefficients at very low methane pressures. An elegant theoretical explanation of this effect has been given by I. I. Sobel'man and his Lebedev colleagues.

Important theoretical results in laser spectroscopy have also come from the laboratory of S. G. Rautian, now at the Spectroscopy Institute. Fast intramolecular relaxation processes in excited states of complex molecules were studied by B. S. Neporent of the Vavilov Optical Institute, and nanosecond and

Two portraits of R. V. Khokhlov (left) and S. A. Akhmanov of Moscow State University, active researchers in the field of laser nonlinear optics. The painting here reproduced in black and white shows a red beam entering and a green "doubled" beam leaving the crystal base.

picosecond laser pulses were used to explore biophysical systems by a Moscow University team of physicists and biologists led by Academician R. V. Khokhlov.

Laser isotope separation

Now attracting considerable attention internationally, both because of their fundamental interest and their potential practical applications, laser isotope separation techniques are based on the fact that the spectral lines of different atomic or molecular isotopic species are often well resolved. Intense monochromatic laser radiation therefore can be used to preferentially excite one species, possibly leading to selective ionization or dissociation.

There has been considerable Soviet activity in this area, including the use of lasers to stimulate chemical reactions, Feld told PHYSICS TODAY. As early as 1967, Khokhlov pointed out that an ir laser could be used to heat the vibrational modes of a polyatomic molecule selectively, and considerable theoretical and experimental work has been carried out in the Basov and Prokhorov laboratories with the aim of using lasers to induce chemical reactions.

At the Spectroscopy Institute Letokhov and R. V. Ambartsumyan, who leads a group studying selective photoprocesses, have done extensive work in the selective two-step photoionization of atoms and photodissociation of molecules. In these techniques a gaseous sample consisting of a mixture of isotopes is subjected to simultaneous pulses from two lasers (or one laser and a conventional uv source); one is tuned to a transition connecting the ground state with an intermediate state and the second, to a transition connecting the intermediate state with the continuum.

The group at the Spectroscopy Institute has developed several techniques in the area of two-step photoionization and photodissociation. In 1971 they achieved selective two-stage laser photoionization of rubidium. (Similar processes are studied in the US by Avco–Everett Research Laboratory and the Lawrence Livermore Laboratory for use in uranium separation plants.) Selective two-step photodissociation of nitrogen isotopes was achieved at the Spectroscopy Institute in 1972, with a separation coefficient of about four. Because of the availability of a wide range of tunable lasers, selective photoprocesses of these types are considered to be of general applicability, not only for isotope separation but for separation of various elements and nuclear isomers.

Recent work at the Spectroscopy Institute has explored the interaction of intense ir radiation with molecular vibrations. In studies of the visible luminescence emitted from a molecular gas after irradiation with an intense resonant CO_2 laser pulse, Letokhov, Ambartsumyan and their co-workers were able to show that, even at very low pressures, one component of the luminescence was emitted without delay. This implies that multiple-quantum absorption occurs even in the absence of collisions. This realization led to the achievement of isotopically selective dissociation of low-pressure gases with an intense CO_2 laser, first in BCl_3 and quite recently in OsO_4 and SF_6. Macroscopic amounts of sulfur isotopes in the latter compound have been enriched by a factor of thousands. This important work has since been duplicated in several US laboratories.

Laser development

Of the many investigations on the physics of laser systems in the Soviet Union, Feld discussed what he considers to be the most important types:

High-power pulsed gas lasers. In recent years a great deal of effort in the US, Canada, the Soviet Union and other countries has been devoted to increasing the energy output of pulsed CO_2 lasers by means of an independent ionizing beam. This has made it possible to sustain discharges in large-volume laser plasmas at high pressures, leading to higher energies (up to 50–100 joules per liter of active medium) and higher efficiencies (up to 25–30%). The Lebedev Institute has made notable contributions in the control of laser discharges with electron and proton beams, and has developed CO_2 lasers with working pressures of up to 50 atmospheres.

In a set of joint studies in 1969, the laboratories of Prokhorov and Velikhov showed that the output power of a low-pressure CO_2 laser (about 10 torr) increased when the active medium was ionized by a beam of fast protons. Electron-beam ionization was later considered, and in 1971 the Basov laboratory constructed a 25-atm. CO_2–N_2 laser with an electron-beam sustainer.

More recently Velikhov and his coworkers developed a quasi-continuous CO_2 atmospheric laser with its plasma


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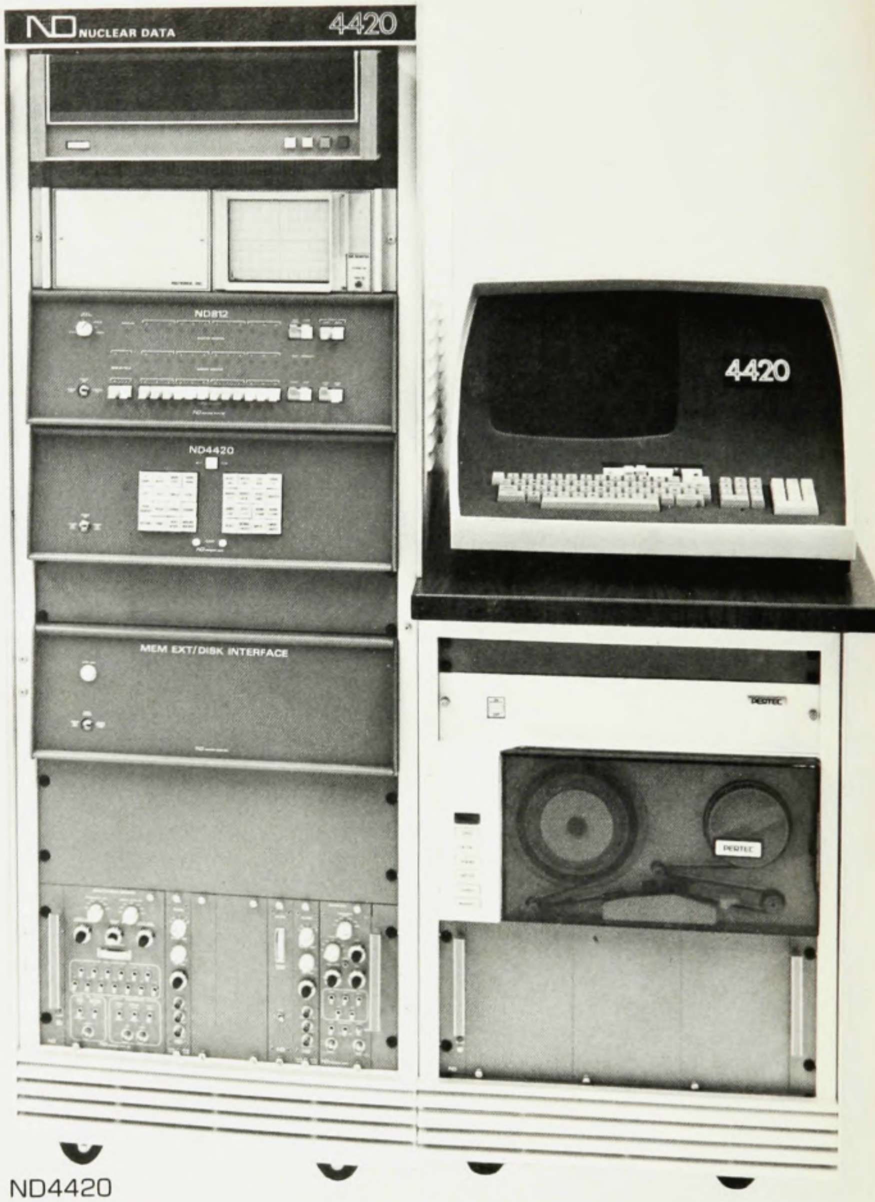

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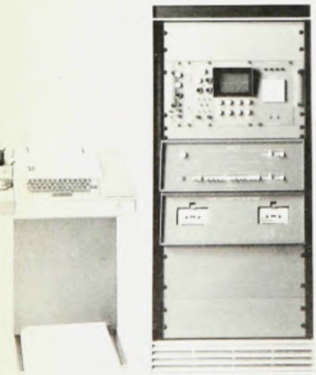

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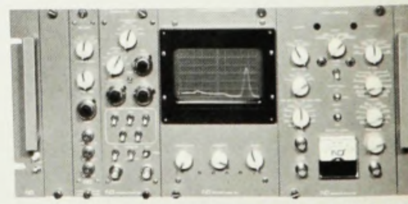

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The American guests in the laboratory of R. V. Ambartsumyan (right) of the Spectroscopy Institute are Michael Feld of MIT (left) and John Hall of the National Bureau of Standards, Boulder.

controlled by a neutron beam. In this way energy of up to 40 joules per liter has been extracted with very long pulses (hundreds of microseconds).

Photodissociation lasers. Another method of obtaining high-power laser pulses is to use molecular photodissociation as an excitation mechanism. As early as 1961, Rautian and Sobel'man pointed out that photodissociation could be used to pump lasers. Basov's laboratory has developed a high-energy iodine photodissociation laser at 1.3 microns excited by light from an electric discharge in the active medium in contrast to the first such laser system, in which an external flash lamp was used. The experimenters at the Lebedev obtained pulses of 720 joules with 60-microsecond duration in an active volume of 150 liters; the efficiency was 0.6%. The Soviets are considering further development of this type of laser for use in their laser fusion program.

Gas-dynamic lasers achieve a population inversion between the working levels of a gaseous medium that is being heated. As the gas undergoes rapid expansion and cooling, the difference in relaxation times of the upper and lower levels brings about the inversion. This mode of excitation is attractive because it directly converts thermal energy into laser radiation. Furthermore, it has led to cw lasers with the highest available output powers.

Gas-dynamic lasers were developed independently in the US and in the Soviet Union, where Prokhorov's lab has been the most active. Work there is directed towards creating a population inversion during the condensation of a supercooled ultrasonic gas flow.

Tunable dye lasers are important because of their wide tuning range and good cw characteristics. A. N. Rubinov's laboratory in the Physics Institute of the Byelorussian Academy of Science, directed by Academician B. I. Stepanov, is the most active Soviet lab in this area. In 1966, Rubinov and his co-workers developed a ruby-laser-pumped dye laser, independent of similar work by P. P. Sorokin in the US and F. P. Schafer in Germany. Systematic studies of the amplifying properties of a wide range of dyes are now being carried out at Minsk.

At Moscow University, Khokhlov and his colleagues have developed optically-pumped organic scintillators as active laser media. One such material, paraterphenyl, gives tunable radiation of the shortest wavelength known at present (3300–3600 Å). Scintillators are particularly important for use in ultraviolet lasers because they are more stable to uv radiation than are dyes.

Short-wavelength laser research is of great interest in the U.S.S.R., as can be seen from the fact that it was a central topic at the three most recent Soviet conferences on quantum electronics. The work includes development of vacuum-ultraviolet lasers and studies of possible methods of constructing lasers in the x-ray and gamma-ray regions. The latter problem is discussed in the article "Prospects for a gamma-ray laser" by G. C. Baldwin and Khokhlov in the February 1975 issue of PHYSICS TODAY.

In 1970 Basov and V. A. Danilychev, Yu. M. Popov and D. D. Khodkevich, using a high-energy electron beam to excite a liquid xenon sample, constructed the first vacuum-uv excimer laser. This experiment has stimulated a great deal of work in excimer lasers in gaseous media. Excimers are molecular systems in which stimulated emission occurs between a metastable level and the dissociative ground state.

Another important vacuum-uv laser, with molecular hydrogen as the working medium, oscillates in the 1600-Å and 1200-Å regions. This type of laser was proposed by G. G. Petrash of the Lebedev Institute in 1965. Following this approach Letokhov, I. N. Knyazev and V. G. Movshev at the Spectroscopy Institute have developed a simple, compact transverse-discharge hydrogen laser. The group at the Spectroscopy Institute has used this device in studies of molecular photoionization and is now considering its use in a sensitive ionization mass spectrophotometer for detecting complex molecules.

The possibility of obtaining uv laser amplification in a recombining plasma has been studied theoretically by L. I. Gudzenko and L. A. Shelepin at the Lebedev Institute and is being pursued by several Soviet experimental groups.

The Lebedev Institute and the Spectroscopy Institute are the main Soviet centers studying the possibility of constructing x-ray lasers. Sobel'man and his colleagues at the Basov laboratory have proposed several methods for creating an inversion between the energy levels of multiply-ionized atoms in a laser plasma, with hopes of obtaining laser radiation in the 50–150-Å region. The Spectroscopy Institute is also exploring the possibility of obtaining laser oscillation at 100–500 Å with multiply-ionized species produced by a two-stage pumping scheme. These efforts are being supplemented by detailed studies of the spectra of multiply-ionized atoms at Basov's and Mandel'shtam's laboratories.

The possibility of gamma-ray lasers, based on stimulated emission between nuclear excited states, is probably being discussed more actively in the Soviet Union than anywhere else. The participation of many prominent Soviet scientists such as Khokhlov, V. I. Gol'danskiy of the Institute of Chemical Physics and Yu. M. Kazan of the Kurchatov Institute, lends credence to this speculative field. Several very difficult problems must be overcome for gamma-ray lasers to be constructed, including:

- The non-uniform broadening of Mössbauer lines must be reduced by 3–5 orders of magnitude;
- methods of rapidly producing high densities of nuclei in excited states must be developed, and
- techniques must be found to grow rapidly a crystalline "needle" of excited nuclei.

The first topic is being studied in Khokhlov's lab, where a special rf technique is being used to reduce the linewidth of Mössbauer lines; techniques for rapidly growing single microcrystals are also being explored there. Many interesting ideas for suppressing the broadening of Mössbauer lines have been suggested by Yu. N. Kagan, who has studied related problems in solid-state and nuclear physics.

Soviet–US cooperation

Despite the fact that there is no formal treaty for cooperation between the Soviet and US governments in this area, Feld feels that it is probably closer in this than in most other fields of science. Soviet biennial conferences on coherent and nonlinear optics traditionally invite the participation of ten representatives of Western countries. The Vavilov Conferences on nonlinear optics, held every two years at Akademgorodok, also invite US participation and American scientists, including Feld, have been included in the organization committee. Similarly, Soviet scientists regularly participate in the International Quantum Electronics Conferences, the Conferences on Laser Engineering and Applications in Washington, the Gordon Conferences on nonlinear optics and numerous other conferences.

In a steady traffic of exchange visits, several American scientists have visited the U.S.S.R. as guests of the Academy of Sciences to present lectures and visit laboratories throughout the country. Over the past ten years almost all of the leading American laser physicists have visited the Soviet Union; several of the scientists interviewed by PHYSICS TODAY had high praise for the hospitality accorded them there. Many leading Soviet scientists similarly have made several trips to the US. In a few cases Soviet scientists have worked in American universities for an extended period. These reciprocal visits are usually based on an agreement between the Soviet Academy of Sciences and the US National Academy of Sciences. They often lead to close personal contact between scientists in the two countries.

American and Soviet scientists are becoming more and more interested in the possibility of conducting joint research in the areas of mutual interest. Prokhorov's laboratory at the Lebedev Institute is establishing a close link with the Los Alamos Scientific Laboratory and the Lawrence Livermore Laboratory; the Spectroscopy Institute of the Soviet Academy of Sciences and the MIT Laser Physics Laboratory are developing a program of joint experimental and theoretical research in laser spectroscopy with ultrahigh resolution. Many scientists in the U.S.S.R. and the US feel that the problem of the gamma-ray laser might be the initial theme for joint research, in view of the complex character and the prospects of the problem.

Javan, whose lab has been host to Soviet scientists for several months at a time, feels that the exchanges are bringing about a healthy situation, enhancing the possibility of cooperative ventures between the Soviet Union and the US. Joint work in projects that require large-scale engineering, such as some aspects of laser-fusion research, could prevent the waste of hundreds of millions of dollars—and rubles—in duplication of effort. □