Education in optical physics at Moscow State University

N. I. Koroteev

Physics Department & International Laser Center, Moscow State University, Moscow 119899, Russia

Modern laser physics, and more general, optical physics is arising now as a new, very important branch of natural sciences with self-sufficient techniques and relevant scope of research. It's methods and ideas have become of general importance for the whole physics as well as for other natural sciences, health services, environmental control, ecology, communications and technology.

More and more people are being involved in making research in optical physics and in it's applications. Laser physicists and optical physics teachers have faced up with very strong and growing demands from both the scientific community and the public to educate thousands and thousands of newcomers to such an extent which is sufficient to support the growing research and business activity in these areas.

This challenge of the society should be met by universities with understanding that the only adequate form of education in this field is such which is based upon recent developments and, even more important, upon modern trends in future developments of physical optics, laser physics and laser technology.

From pure physical point of view, the most important trend of nowadays consists in the formation, on the basis of physical optics and, in some respect, instead of it, a new self-consistent brunch of physics, *optical physics*.

In a zero-order approximation, the scope of optical physics is the same as that of laser physics. It means that characteristic features of optical physics are the use of laser radiation of all kinds in the experiments and use of relevant for laser physics mathematical techniques and conceptual language.

However in the next approximation optical physics looks even more general and more fundamental than laser physics does because in the scope of the former all processes and all kinds of material's forms and aggregation states are included. Matter consists of atoms, molecules and crystals with the binding energy in the scale from fractions up to several units of electron-volts (optical range of binding energies). Laser radiation manifests itself as the most general and convenient tool of investigation of processes inside matter. Recent magnificent progress in laser physics allows an experimenter to generate ultimately short laser pulses with time duration of the same order as the period of optical oscillations (for the characteristic binding energy in the order of 1 eV the optical period is in the order of few femtoseconds, $1 \text{ fs} = 10^{-15}$ s). In combination with commonly used broad tunability of laser radiation throughout the whole optical range (from IR through visible up to UV frequency range) this circumstances create a unique situation in physics when the whole class of substances and processes in them may be studied in a unified way with unified experimental equipment and with basically unified conceptual background.

To clarify the main trends in modern optical (laser) physics we should take into consideration the programs and lists of topics of recent major conferences and symposia in this field.

Among these conferences are IQEC's (International quantum electronics conferences), CLEO/QELS's (Conferences on lasers and electro-optics together with quantum electronics and laser sciences), ICONO's (International conferences on coherent and nonlinear optics), UPS's (Symposia on Ultrafast phenomena in spectroscopy), UP's (Conferences on Ultrafast processes), OE/LASE's (Conferences on opto-electronics and laser science and engineering) and others.

Close inspection of the programs of these major international conferences will easily show that the list of "hot points" of optical physics in recent years consists of the following topics: * Superstrong optical fields
* Ultrafast (femtosecond) processes
* Laser spectroscopy and its applications in physics, chemistry, biology, ecology, etc.

* Quantum optics
* Surface optical phenomena
* Experiments with single atoms, ions and/or molecules
* Advances in several branches of experimental laser techniques: new generations of solid-state lasers including diod-pump lasers, "intellectual" (adaptive) lasers, miniaturization of lasers, etc.
* New ideas in optical computers: neural networks, all-optical associative memory, ultrafast binary elements, etc.
* Practical applications in optical communications and information processing
* Laser applications in life sciences and environmental control.

The consequences of this inspection are straight forward: the modern educational course of optical physics should be oriented in such a way which will allow a student to become able in the end to work professionally in any of the above mentioned fields. The orientation of the teaching course to the recent advances in optical physics will also create an additional interest among students during the education.

A good example of modern textbook on general optics with the output into the realm of optical physics is that of the late prof. S A Akhmanov's book, which had been finished just on the eve of his unexpected and untimely death on July 1, 1991. The list of contents of the book is as follows:

General Optics
by S. A. Akhmanov (to be published by Nauka Publishers, Moscow)

1. Introduction: historical comments. The main idea of the book: up-to-date laser optics, optical physics.
2. The fundamentals of electromagnetic theory of light.
3. Radiation: optical generators.
4. Modulated optical oscillations and waves; random processes and fields.
5. Interference and diffraction, coherence of light.
6. Light-matter interaction: linear and nonlinear response, optical diagnostics, strong laser action on matter.
7. Light waves in media: gases, liquids, solids.
8. Elements of applied optics.

Supplement: historical materials,copies of most important original papers.

This book is based on a general course of Physical Optics, which prof. S A Akhmanov has usually delivered to the 2nd year students of Physics Department of Moscow State University.

What is of ultimate importance in teaching optical physics is clear understanding of the experimental nature of the subject. That means that not only theoretical course are to be delivered to students but also a specially designed and carefully accomplished series of practical laboratory problems should be included in the education.

We in R. V. Khokhlov's Nonlinear optics lab and in International Laser Center of Moscow State University have created such laser teaching laboratory. The short description of 7 problems included in this teaching lab is placed below.

1. LASER TEACHING LABORATORY

This lab is created in Physics Department and in International Laser Center of Moscow State University. Third and fourth year students study at this lab and post graduate students and students of Short laser courses work there as well.

Firstly, the students get the knowledge of the basic principles of lasers and nonlinear optics by making model experiments with the help of analog and digital computers. Then they make real physical experiments using teaching set-ups which look like real physical experimental set-ups.

They perform different operations: alignment of optical systems, tuning different devices, working out the techniques of making experiment and analyzing the experimental data. In this lab students acquaint themselves with different kinds of lasers and nonlinear optical devices, with different laser operation regimes, and they gain some experience in working with different measuring devices and computers.

1.1. Nd:YAG laser radiation kinetics

The purpose of this laboratory experiment is to acquaint students with the principles of a solid state laser action and its construction. Two regimes of laser action are investigated in this work, i.e. a continuous wave regime and a *Q*-switched one.

Firstly, the students align the laser elements and observe laser generation.

Secondly, they measure the laser generation threshold and then obtain the experimental dependence of relaxation oscillations frequency on pump power.

In the *Q*-switched regime the giant pulses parameters are measured (pulse duration, peak power) and a sharp increase in second harmonic generation (SHG) efficiency in $LiNbO_3$ crystal is observed (ın a comparison with free - running regime).

1.2. Ultrashort light pulses generation and measurement techniques

The continuously pumped solid state Nd:YAG laser with double acousto-optic modulation and mode-locking, and correlation methodology of ultrashort light pulse duration measurement are studied in this laboratory experiment.

The students investigate all possible operational regimes of this laser, such as continuous wave, *Q*-switched, active mode locking, simultaneous *Q*-switched and mode locking ones. They measure average radiation power in all regimes, the pulse duration and peak power of giant pulses in *Q*-switched, the pulse duration of ultrashort light pulses and its dependence on resonator length detuning.

The important advantage of this work is the use of up-to-date measuring apparatus. A personal computer in this case is used for controlling the optical correlator and for obtaining and analyzing experimental data.

1.3. Optical harmonics generation

Such nonlinear optical effects as SHG and optical mixing are studied experimentally in this laboratory experiment.

In the beginning the main factors determining the efficiency of an optical doubler are studied. For this purpose the dependence of optical doubler efficiency on laser radiation power is measured in different nonlinear crystals (KDP, $LiIO_3$, $LiNbO_3$). Then the value of relative nonlinearities of these crystals are calculated by using the experimental data.

In the second part of this work the operation of a two cascade generator of the third and or the forth harmonics is studied.

The important feature of this work is the use of a personal computer for obtaining and analyzing the experimental data and for controlling an experimental set-up.

1.4. Optical parametric oscillator

This laboratory experiment is concerned with one of the basic non-linear optical phenomena, an optical parametric oscillation. In this laboratory experiment students acquaint themselves with two nonlinear optical devices: an optical doubler and an OPO, the source of wide range tuned coherent optical radiation.

Firstly, the OPO resonator is aligned.

Secondly, the OPO operation threshold is measured, and then the OPO-tuning curve (the dependence of radiation wavelength on the angle between the laser beam and the crystal axis) is obtained.

1.5. CARS-spectrometer

In this laboratory experiment students can carry out modern laser experiment and obtain results presenting scientific interest. The spectrometer includes a laser part which consists of an industrially ready-made laser and an original home-made dye laser.

A personal computer is used for obtaining, storing and analyzing experimental data, and for controlling the spectrometer as well.

In the experimental part of the laboratory work the students obtain the CARS-spectrum of a model object (heated air, N_2, mixture of isotopic molecules, etc.). Advanced students can conduct scientific research; each time a new object being offered. Optical Modulators

In this laboratory experiment the students study the principles of optical radiation modulation. They study the operation of two types of optical modulators: the electro-optical and acousto-optical ones. As a source of radiation a helium-neon laser is used. First they measure the dependence of transparency of a Pokkels cell on the electric field strength and the half wave voltage for this cell. Then they calculate the value of the electro-optical constants. Then the acousto-optical modulator is studied. The students measure the Bragg angle and its dependence on the acoustic wave frequency. Finally they measure the phase matching angle width and study the dependence of diffraction efficiency on the acoustic wave power.

1.6. Holography

This laboratory experiment acquaints the students with the practical method of recording holograms of real objects. The students must build a simple experimental set-up by using different optical and optomechanical elements, align them and then make the hologram of a real object. After developing a photoplate they observe virtual or real holographic images of this object.

The basic educational course on optical physics for undergraduate students is accompanied by a number of special courses on nonlinear optics, laser spectroscopy, interaction of laser radiation with matter, resonant processes, ultrashort laser pulse generation and measurements, laser biophysics. These courses are available for students on their choice. Some of these courses are also available for graduate students and students of "refreshing" courses for engineers, medical doctors, school teachers etc. who are intended to enter laser physics and laser techniques.

Additional educational possibilities are opened up due to the series of short laser courses which are under a special sponsorship of MSU International Laser Center. In 1991, this short courses were incorporated in the program of ILC's Laser graduate School. The list of lectures and topics of the short courses are given below.

* Laser Experiments with Single Atoms and the Test of Quantum Physics;
* Laser Induced Instabilities and Defects Generation on Surface of Solids;
* Laser Spectroscopy of Ozone;
* Eximer Laser and Applications;
* Laser Deposition of Thin Films;
* Nonlinear Time Resolved Spectroscopy in Condensed Matter;
* Multi Stability, Instability and Fluctuations for Optical Wave-processes in Spatially Periodic Medium with High Threshold Nonlinearity;
* Laser Optoocustics of the Semiconductors;
* Laser Spectroscopy and Vibrational Relaxation in Crystals;
* Photothermal Study of Geterogeneous Materials;

* Photothermal Methods to Semiconductors Characterization;
* Nonlinear Optics;
* Optical Synirgetics and Neural Networks.

In conclusion the optical physics has become a self- consisted brunch of physics with numerous applications in other natural sciences and in technology. Both academic demands, and the challenge of the society have created a necessity of improved optical education based on recent advances of laser physics and laser technology.

A set of theoretical courses together with laser teaching laboratory have been developed at the Physics Department and International Laser Center of Moscow State University.