Optics Teaching of Mathematical Students at M. V. Lomonosov Moscow State University in Courses of Theoretical Physics

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ABSTRACT

The concept of teaching in optics and methodical problems of mathematical student's education are discussed. The fundamental knowledge on modern mathematics and of computer-based methods of investigations acquired by students at the first years allows our professors to represent the different branches of optics and photonics at the high scientific level. The methods of teaching have resulted from the more than thirty year's experience of work of the Chair of General Physics and Wave Processes staff of M. V. Lomonosov Moscow State University on training the mathematical students.

Keywords: teaching scheme, mathematical models of optical phenomena, inductive method of presentation, computer-assisted demonstrations

1. INTRODUCTION

M. V. Lomonosov Moscow State University was founded in 1755 and since that time has been playing an outstanding role in education, science and culture in Russia. At the present moment there are more than 9,000 professors, lectures and research associates working at MSU. There are 148 members of Russian Academy of Sciences (including several Nobel Prize winners) and over 8,000 Doctors of Science and Candidates of Science (Ph. D.). More than 28,000 undergraduate students and about 8,000 graduate students study in 22 faculties. Each faculty consists of a number of departments (chairs) headed by prominent professors and scientists. Every chair conducts scientific research and some of them are known not only for teaching but also for fruitful research activity. The university library contains more than 10 million volumes.

The oldest University of Russia has a long-time tradition of mathematical education. The Department of Physics and Mathematics was set up in 1804. Its development has led to the creation of Faculty of Mathematics and Mechanics in 1933, Faculty of Physics in 1933, and Faculty of Computer Science and Cybernetics in 1970. The school of mathematics in Moscow State University is world known for the works of Nicolai Lusin, Andrei Kolmogorov, Ivan Petrovskii, Andrei Tikhonov, Mstislav Keldysh and other prominent scientists.

2. FACULTY OF MATHEMATICS AND MECHANICS AND FACULTY OF COMPUTER SCIENCE AND CYBERNETICS

Nowadays, Faculty of Mathematics and Mechanics is one of the main centers of mathematical thought. It consists of two parts: Division of mathematics and Division of mechanics. More than 1,800 undergraduate students study during 10 semesters for Master Degree. The faculty staff consists of nearly 400 professors, lectures and well-qualified researchers. Beginning with the third year of study student's research is carried out supervised by a Professor of the Faculty in a special field of science.

Faculty of Computer Science and Cybernetics separated from Faculty of Mathematics and Mechanics more than 30 years ago. It trains approximately 1,900 students for Master Degree during 10 semesters. Beginning with the third year of study, students major in special fields of science and receive deeper training in Computer Systems, Mathematical Methods of Physics, Mathematical Statistics, and Informatics. At the present time there are 12 members of Russian Academy of Sciences and over 350 professors, Doctors of Science and Candidates of Science (Ph. D.) working at the Department of Computer Science and Cybernetics. It is necessary to stress a very high educational level of students studying in these mathematical Faculties. During the entrance examination the competition is more then 12 persons for one position. According to statistic data, about one fourth of undergraduate students continue their education at the postgraduate level. Annually, the students publish about 100 articles in various scientific journals.

Seventh International Conference on Education and Training in Optics and Photonics,
Tuan-Kay Lim, Arthur H. Guenther, Editors, Proceedings of SPIE Vol. 4588 (2002)

Unfortunately an alarming tendency of cutting down of general number of lectures, seminars, and laboratory exercises for teaching physics to students training mathematics is being observed. In the first place it is proved to be in reduction of the education time in teaching scheme, allotted for optics as a part of general physics course. The main reason of it is a popular among professors of mathematics point of view, that it is easier and more natural for mathematical students to analyze the mathematical models used to describe the electromagnetic waves propagation and wave interaction with matter. In other words the deductive method of presentation, which is characteristic for courses of theoretical physics, is more preferable for students specialized in mathematics than the inductive method generally used in courses of general physics. Hence it is expediently to consider optical effects as a particular case of some more general physical phenomena, investigated in electrodynamics and physics of wave processes.

2.TEACHING SCHEME

Physics courses at the mathematical Faculties of MSU have the aim of giving to the students the general education in Sciences on one hand, and providing a more specialized education in Physics on the other hand. These courses present fundamental laws, basic ideas and methods of classic and modern Physics. The courses of Physics at the Faculty of Mathematics and Mechanics and Faculty of Computer Science and Cybernetics are taught one and a half and two years, respectively. Unfortunately, they take only 3 per cent and 5 per cent of time allotted for all education process, correspondingly.

However mathematical students have to know the real situation in the investigation of the hot points of modern physics. Due to the lack of time for physics it is necessary to turn to the qualitatively other level of teaching. We have to discuss with students the physical models used in various sections of physics and to show them the limitations of the appropriate approaches. As a result we have to open to students the nature of this limitation and to denote the ways of construction of more rigorous theories. In this way the unity and interrelation of various sections of physics is coming to light for the students.

As a result of this point of view in Faculty of Mathematics and Mechanics the course of Physics structurally includes the following sections. The course of General Physics includes thirty-two lectures and twenty-four seminars in the second and the third semesters. In other words it is one hundred and twenty academic hours for all General Physics. Optics is the part of General Physics. The course of theoretical physics is in the ninth semester. It consists of Quantum Mechanics (16 lectures and 8 seminars) and Statistical Physics (16 lectures and 16 seminars). It is only one hundred and twelve academic hours.

In Faculty of Computer Science and Cybernetics the whole course of General Physics and Theoretical Physics is conventionally divided into several sections: Mechanics, Electricity and Magnetism, Statistical Physics and Thermodynamics, Physics of Wave Processes, Basic physics of computers, Quantum Mechanics and quantum computing. The first and the second sections are delivered to all students. Only the students who specialize in the fields of mathematical Physics, Computer Methods, Research Automatization, Nonlinear Dynamic Systems and Processes of Control, and General Mathematics study Physics of Wave Processes. Students of these branches are taught the different parts of Theoretical Optics included in the sections of Electricity and Magnetism, Quantum Mechanics and quantum computing, and Physics of Wave Processes.

3. PROGRAM OF OPTICAL EDUCATION AND METHODS OF TEACHING

Methods of teaching the different aspects of optics are mainly based on both the students good knowledge of Mathematics obtained at the University and their knowledge of Physics gathered in school. Formation of the integral notion about fundamental principles of light interaction with matter and getting familiarity with the basic ideas of modern optics are based on the use of methods of Mathematical Physics. Special emphasis is placed upon construction of mathematical models of optical phenomena, and physical interpretation of the results obtained. In these courses we show students close connection between physical ideas and corresponding mathematical models used to describe them. During the lecture courses the inductive method of presentation, which is characteristic for courses of General Physics, and the deductive method generally used in courses of Theoretical Physics are efficiently combined. Such approach is of special importance for optical education of students specializing in Mathematics. We also efficiently use physical and computer demonstrations.

The optical education of mathematical students is divided into two levels. All students of both Departments take the program of the first level. We start from Maxwell system of equations for electromagnetic field in a medium and the material equations for the optical spectral region and introduce the wave equation for electric field strength, the expressions for energy and Poynting vector. Solution of wave equation is discussed in details. Using the boundary conditions for temporal and spatial Fourier components of electromagnetic field we consider the problem of light reflection from the surface of an isotropic medium (Snellius law, Fresnel formulae). After that, the notions of spatial and time coherence are introduced. Using simple examples we discuss such problems as interference, Huygens-Fresnel principle, diffraction and dispersion of light. The conception of the light polarization and consider the propagation of elliptically polarized light during crystal and optically active media are given. We obtain a parabolic equation for slowly varying amplitude of the wave and consider propagation of light with Gaussian profile.

All these problems we consider in the course of optics at Faculty of Mathematics and Mechanics. It takes eight or nine lectures to deliver to high qualified in Mathematics students of this department the parts of optics mentioned above. We also consider these problems at Faculty of Computer Science and Cybernetics as a part of electrodynamics. Some parts of Theoretical Optics at the both Departments are delivered in the course of Quantum Mechanics (quantum theory of light generation, quantum theory of dispersion etc.). They take about ten fifteen per cent of total time allotted for this course.

Only the students who specialize in the fields of mathematical Physics, Computer Methods, Research Automatization, Nonlinear Dynamic Systems and Processes of Control, and General Mathematics study Physics of Wave Processes at Faculty of Computer Science and Cybernetics have the second level of optical education. In the course "Physics of Wave Processes" we consider definition of wave and wave process, transmission of energy by the wave, one-dimensional wave equation, simple harmonic wave, the spatial and temporal scales, and plane, cylindrical and spherical waves. Speed of light, linear, circular and elliptical wave polarization; natural light, electromagnetic energy, intensity, matching conditions on the electromagnetic waves on the boundary of two media are the subject of the second lecture. After that we consider amplitude modulation, frequency spectrum, pulse duration and its spectral bandwidth. We introduce to students the problem of frequency and spatial dispersion. We tell them about the first-order approximation of dispersion theory, group velocity, transfer equation of wave packet, normal and anomalous dispersion, second-order approximation of the dispersion theory, and wave equation in parabolic approximation. Here we consider optical activity, gyrotropy, and spatial dispersion, electronic theory of dispersion of light, anomalous dispersion, wave dispersion in plasma. After that the boundary conditions, refraction and reflection laws, fiber optics, fiber communication lines are considered.

In the sixth lecture we tell students about interference of two monochromatic waves, superposition of plane waves, interference of waves emitted by point sources, Michelson interferometer, standing waves. The coherence problem is the subject of the next lecture. In the ninth lecture we consider the mathematical statement of the diffraction problem, Helmholtz-Kirchhoff integral theorem, Sommerfeld principle of limiting amplitude, Fresnel-Kirchhoff diffraction formula, Huygens-Fresnel principle, Fresnel's zones. Parabolic approximation in diffraction theory is the subject of the next lecture. Here we consider Fresnel diffraction, wave equation in the parabolic approximation, diffraction of plane waves, an angular spectrum. Near-field and far-field zone of diffraction, the geometrical optics approximation, Gaussian beam are introduced to students. And during the final lectures we consider lasers and basic mathematical models in nonlinear wave optics. Here we tell students about wave interaction in nonlinear dispersive media, phase matching, harmonics generation, parametric interaction, self-action of light waves, Nonlinear Schrodinger equation, pulse self-phase modulation and beam self-focusing. We also say about laws of conservation and their role in the numerical simulations and give an overview of basic methods for numerical investigations.

It can be seen that the optical teaching is carried out in close connection with general analysis of wave phenomena in Nature. The course includes main notions of wave theory such as plane wave, harmonic wave, polarization, and energy flow. The physical picture of the wave propagation takes the central position in this course. Much attention is given to spectral analysis because this method is widely used in optics and in numerical experiments. The equivalency of spectral and temporal approaches in wave processes presentation is shown. Use of spectral method allows us to consider wave propagation and traditional numerical schemes from similar points of view. A bright example of it can be seen in analysis of spatial dispersion of the wave in discrete structures and dispersion of the finite-difference numerical schemes for wave equation. Along with classical optics we discuss some problems of nonlinear optics. In parallel with wave propagation in a nonlinear medium we discuss a few methods of numerical integration of the Nonlinear Schrodinger equation.

Lecture demonstrations are useful for illustration of wave propagation in different medium, phenomena of electromagnetic wave polarization, formation of wave packet by harmonics addition. They are used to demonstrate normal and anomalous dispersion, phenomena of interference and diffraction, the reflection of electromagnetic waves, and high sensitivity of interferometric measurements. Some experimental demonstrations show laser generation, high power density and small divergence of laser radiation, nonlinear effects of second harmonic generation and stimulated Raman scattering. We efficiently combine physical demonstrations with computer demonstrations of physical phenomena. We believe that for Computer Science students it is of great importance to be familiar with computer abilities in simulations of physical phenomena. A lecturer takes the opportunity of putting together theoretical presentations, physical demonstrations, and numerical experiment. According to our rules each student receives two or four problems of different degree of difficulty. They have to work through the problems themselves and present their own understanding while submitting the results to the tutors. This method helps students to learn working under specific optics problems and to use of necessary scientific literature and reference sources. On tutorial seminars teachers analyze typical problems, answer students' questions concerning their individual work. Two colloquia are meant to present solutions of the problems and discuss physics behind them.

4. Laser Graduate School on Modern problems of Laser Physics

The students of both faculties having excellent marks in optics and going to be engaged in scientific work are invited to take part in Laser Graduate School on Modern problems of Laser Physics. Every year International Laser Center of Lomonosov Moscow State University organize session that lasts for one or two weeks and consists of short courses (two or eight hours each). The instructors who are the top scientists in the specific research through all over the world deliver these courses. Each course is focused on a selected scientific subject and covers the introduction to the discussed field, some history, major and up-to-date results, new perspectives, and key references. Thus, a short course is basically an overview of the selected subject given by a top specialist in this field. This is an opportunity for the students (graduate students, young scientists, etc.) to ``touch" the Science not just reading the papers in scientific journals, but attending the instructor's courses, talking to them, asking questions. We came to the idea of focusing the every session or the Workshop of the LGS on a selected, quite narrow field. This helped us a lot in attracting the best instructors that could cover the subject of the Workshop completely. The list of Workshops is given below.

1. 1991, Workshop on laser biophysics
2. 1992, Workshop on modern problems of laser physics
3. 1993, Workshop on photoacoustics
4. 1994, Workshop on nonresonant interaction of laser radiation with matter
5. 1995, Workshop on surface and interfaces
6. 1996, Workshop on imaging trough the atmosphere
7. 1997, Khokhlov tutorials
8. 1998, ICONO’98 short courses
9. 1999, Akhmanov tutorials
10. 2001, Modern problems of coherent and nonlinear optics

We create a special atmosphere of the School close to that one of the regular scientific meetings and therefore help students in raising an experience in scientific communications. Among the ILC LGS instructors were H. Walther, N. Bloemberhen, C. Flytzanis (France) T. Bloembergen (USA), H. Walther (FRG), C. Flytzanis (France), A. Boccara (France), A. Nevell (USA), A. Laaksonen (Sweden), C. Rulliere (France), H. Coufal (USA), L. Favro (USA), A. Mandelis (Canada), J. Murphy (USA), H. van Driel (Canada), T. Heinz (USA), T. Furtak (USA), R. Byer (USA), E. Ippen (USA), C. L. Tang (USA), G. I. Stegeman (USA), R. Miles (USA), P. Corcum (Canada) and many others.

6. Conclusions

The Chair of General Physics and Wave Processes of Physics Department of MSU has been realizing these forms of optical education of mathematical students at M. V. Lomonosov Moscow State University[1-4]. This Chair was established in 1978 by now late professor Sergey Akhmanov. The Chair of General Physics and Wave Processes has inherited the tradition of scientific excellence from R. Khohlov scientific school and Sergey Strelkov scientific school.

From 1991 up to 1998 Nikolai Koroteev headed the Chair. Today 67 full-time professors, associate professors, assistant professors and researchers possessing Dr. Science and Ph.D. in physics and mathematics are working at the Chair of General Physics and Wave Processes. In different years all of them make theirs contribution to optical education of mathematical students. I am very grateful to all my colleagues. We are proud of our modest contribution to preparing high-class graduates successfully working in the field of computer simulation in nonlinear optics.

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