Go photonics, go!

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What is light? – what a question, everyone knows that. Is this really the case? Try asking several different people and you get as many answers as the number of people you asked. Some will say light drives all life on earth, others will stress the role of light in our reception of the real world, still others will notice how light inspires poets and artists. Although each reply will be obviously correct, none will provide a full answer to the question. No wonder that light, being an eternal source of fascination for so many people, has been a long-standing challenge also for scientists. In particular, physicists have tried to explain *what is light* for a very long time. While no special knowledge is needed to use light, revealing its nature kept the best brains busy for centuries. It is enough to mention such scholars as Newton, Einstein, though also Johann Wolfgang von Goethe, who was not only the great romantic poet but also, which is less known, an outstanding scientist whose treatise "Zur Farblehre" has made a profound contribution to the history of science. The breakthrough in our understanding of light happened already in the 19th century, mainly due to the work of the theorist James Clerk Maxwell and experimentalist Heinrich Hertz. Yet, it was only recently that the puzzle of light was solved completely: the 2005 Noble Prize for Roy Glauber for his quantum theory of light has finally brought the issue to a close.

When we already understood the nature of light, it became possible to study various ways of its generation, to learn how to detect it and tailor it to our specific needs. This used to be the natural field of optics and of atomic and molecular physics. These disciplines were, and still are, actively developed in Poland. In the Jagellonian University, systematic research in this field started after World War II when massive migrations forced by the new geo-political conditions brought Professor Henryk Niewodniczański (1900–1968) from his native Vilnius to Kraków. Professor Niewodniczański contributed very much to the development of physics in Kraków and, in particular, to *atomic optics*, i.e. the optical spectroscopy of atoms. In 1962 within the Institute of Physics of the Jagellonian University he founded the Department of Atomic Optics headed by Professor Danuta Kunisz (1924–1979), a former Niewodniczański's student. This was the beginning of modern research in the field of optical and atomic physics in Kraków. Thanks to the development of lasers the field flourished in the seventies and attracted many young enthusiasts. The enthusiasm was indispensable to pursue experimental research in Poland at that time, since equipment was so scarce that nothing could be accomplished without a great deal of optimism and devotion. Despite these difficulties, unlike our colleagues in other East-European countries, we were fortunate enough to be able to travel and cooperate with the best groups in the world. Many of the scientific and personal contacts of that time have lasted until now.

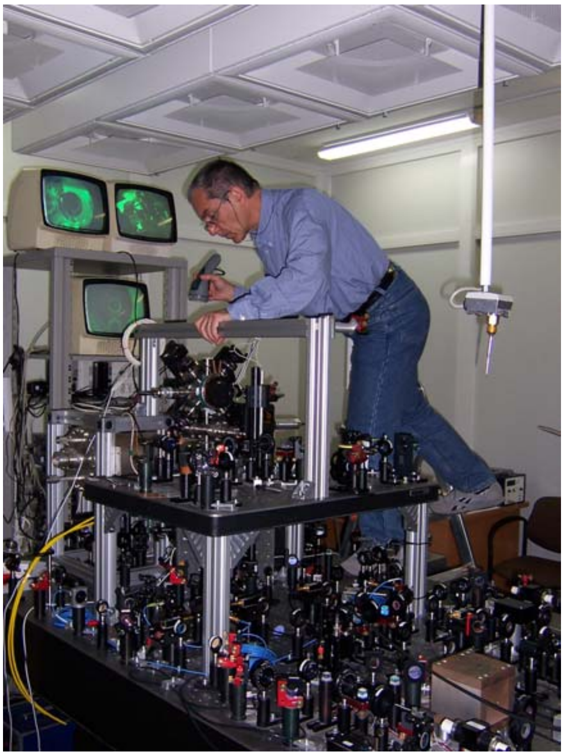
Lasers are very remarkable light sources. Laser light is entirely man-made, and practically does not exist naturally in the universe (though stimulated emission and laser action does occur in some astronomical systems). It has really unique features: coherence, high intensity, high degree of collimation and it can be generated at a very well defined color (monochromaticity) that can be finely tuned to induce resonant interaction with any atom. Such features, on the one hand, allow one to precisely study various aspects of interaction of matter with strong electromagnetic fields and, on the other hand, to modify atomic/molecular properties, control chemical reactions, exert mechanical forces on atoms, molecules and living objects and can be used to manipulate their movements. Thanks to these extraordinary features new disciplines emerged, like quantum and nonlinear optics or the new-born and rapidly expanding photonics. The term *photonics* is not well defined. Attempts to provide an accurate definition fail due to the fast evolution and constant expansion of the field. In general, it can be understood as the creation, transmission and transformation of information via photons, just as it is done by electrons in the case of *electronics*.

The rapid development of optics and photonics is caused by several factors. Firstly, the new light sources and optical methods are far cheaper than accelerators and huge research centers, yet they provide scientific results equally important for fundamental science. It suffices to mention the numerous Nobel Prizes in physics and chemistry (four prizes in the last eight years!) for research based on optical methods. Secondly, optical methods are very versatile and are frequently applied in other fields. This contact of various techniques and approaches results in new interdisciplinary research fields, like nano-photonics, bio-photonics, as well as in novel applications, e.g. in computers, laser printers, optical memories, optical fiber techniques for data transmission, precision instrumentation for measurements of all kinds, medical diagnostics and therapy, etc, etc.

The PHOTON reader can follow the activity in photonics on the example of the Kraków physicists of the Photonics Department of the Jagellonian University.

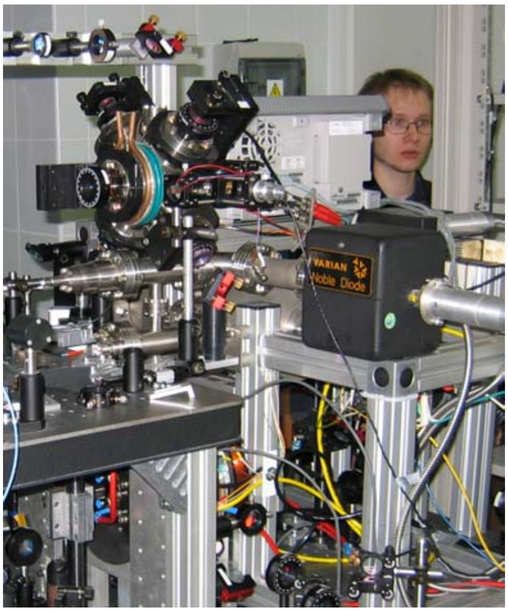
The Photonics Department of the Jagellonian University consists of several research groups. One group has many years experience in plasma diagnostics based on precision laser spectroscopy. These methods are important for the characterization and control of many technological processes, e.g. thin diamond layers. To obtain materials of desired characteristics it is necessary to have full control over plasma sources at temperatures of several thousands of degrees where many complex, not completely revealed physical processes take place. One sensitive method of studying such systems has been worked out at our Photonics Department and is successfully applied also in several foreign labs.

While the plasma diagnostics group employs lasers for the studies of extremely hot media, another group in the Photonics Department uses lasers to reach extremely low temperatures, a few microKelvins above absolute zero. In temperatures so low – much lower than those in outer space – matter exhibits some very unusual features which are extremely interesting and useful for solving many problems of contemporary physics, like superfluidity and superconductance. These features are also important for many fascinating applications such as the construction of novel computers. It is noteworthy, even to many physicists, that the ultra-low temperatures are obtained with the help of lasers which are commonly known as a source of energy and heat, rather than a cooling device.



As can be seen, low temperature research has reached a really high level...

Nonlinear magneto-optical phenomena induced by coherent laser light are the next field of research pursued in the Department. These phenomena seem to have an even wider application potential than cold matter, in particular in emerging quantum information. In quantum computers, the elementary portions of information are specifically prepared quantum states, the so called *qubits*, as opposed to standard *bits* used in contemporary computer science. The difference is very profound and reflects different logical operations that can be performed with qubits (*see the article by Szymon Pustelny on quantum computers in Foton 81*). The novel logic may in future allow a much faster operation of quantum computers. Although quantum computers are still to be constructed, a related field of quantum information, quantum cryptography, has already found its way into commercialization, proving that quantum information is not merely art for art's sake. Another important application of nonlinear magneto-optics are sensitive measurement instruments. For example, precision magnetometers whose principles are developed in the Photonic Department will be able to search for natural resources, to scan the oceans for submarines or to detect hazardous materials, be they single bacteria like anthrax or explosives. On the other hand, ultra-sensitive optical magnetometers can be used for the non-invasive monitoring of cardiac and/or brain action.



The heart and brain of the apparatus

Medical oriented research on the effects of laser light on elementary biomedical processes, the properties of various vital substances and function of organisms is developed in cooperation with different teams of medical and/or biological specialists. We are particularly interested in processes where light acts as the catalyzer of specific chemical reactions that control certain biological processes in tissues and organisms. A familiar example of such a process is *photosynthesis* which is a continuous challenge to scientists of various disciplines. A very attractive discovery to medicine, particularly important for cancer treatment, is the so called *photodynamic therapy* and *diagnostics*. It is based on administrating a special drug to the patient body. The drug has two important features. First is the ability to concentrate in tumor tissue, rather than in healthy cells, the second is that after being activated by illumination with light of an appropriate wavelength the drug triggers a chemical reaction which destroys the tumor without affecting the healthy tissue. While the basics of the photodynamic reaction are widely known, its practical application requires detailed studies combining the knowledge of physics, especially optics and photonics, with medicine.

Another kind of research developed in the Photonics Department are studies of optical and photonics materials. The unique apparatus and sophisticated methods developed for many years, primarily for fundamental research, are now very useful for such application studies. We start cooperation with some development companies and are heading towards closer contacts with hi-tech industry.

Undoubtedly, now is a good time for photonics. In Kraków this field has great traditions and excellent prospects for further development. We do hope to take advantage of both and encourage all who would like to help us to start studies in physics or material science, and then to specialize in photonics.

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