Examples of Future Optical Science and Engineering Undergraduate Research Projects in 2003

b.2. Description of Sample Student Research Activities

b.2.1. Projects in Quantum Optics

The Quantum Optics and Laser Physics research activities includes work in the research groups of Professors Govind Agrawall, Nicholas Bigelow, Joseph Eberly, Carlos Stroud and Emil Wolf, in theorical physics, and Professors Nicholas Bigelow, Robert Boyd, Jonathan Howell, Carlos Stroud, and Ian Walmsley, in experiment, as well as several research faculty, postdoctoral fellows, and more than 15 graduate students. The projects below are typical of the work to be done by undergraduate students in the REU program.

Experiments in Laser Cooling and Trapping and Coherence Effects in Quantum Optics (*Bigelow, Walmsley*). The experimental techniques used in these laboratories include ultra-fast pulsed lasers, laser spectroscopy and high-frequency electronics, as well as signal measurement and analysis. Students who join the group develop a broad base of technical experience in optics, high vacuum systems, and electronics, and at the same time, are trained in the concepts of atomic and optical physics and in nonlinear optics. The project includes aspects of both laser science and atomic and molecular physics. Within the broad subject area -- laser cooling and trapping of neutral atoms and light pressure physics -- two main activities are currently underway. The first major activity concerns the application of high precision and ultra-fast spectroscopic techniques to the study of ultra-cold collisions in traps. The second major activity is the cooling and trapping of two different atomic species in a single optical trap. Here the research is also concerned with collisional physics, molecular formation and the transport of energy between the two atomic systems. Another important goal of this project is the achievement of Bose-Einstein condensation in a binary system. Stimulated by the presence of graduate research students, the undergraduates in Bigelow's lab find themselves part of a supportive yet challenging environment. To date these undergraduates have gained skills in optics, electronics, and machine-shop practice, and they will definitely be at a strong advantage in pursuing graduate programs in physics. Important components of the organization of this group are weekly group meetings and a weekly informal seminar series, “Photons After Dark”; undergraduates in the group are expected to participate actively in both of these functions.

The group is also currently studying quantum interference effects involving the photon pairs produced simultaneously in an entangled state in the process of parametric down-conversion. These photon pairs allow one to study locality violations and the significance and interpretation of the quantum state. Bigelow's group recently proposed to carry out time-resolved interference experiments with down-converted photons that are expected to exhibit certain delayed-choice features. Aspects of this project are being conducted in collaboration with the group of Prof. Ian Walmsley of the University's Institute of Optics. The group has recently developed a new operational approach to the problem of identifying the phase of a quantized electromagnetic field, and has had substantial success in testing the new approach against experiment. So far, however, no experiments with non-classical states of light have been done. A possible project is to use the entangled photon pairs produced in the parametric down-conversion process as input to the phase measurement system, and to test theoretical predictions. Finally, the group is investigating the fundamental aspects of quantum noise for the collective atomic spin of an atomic gas. Using a quantum non-demolition measurement approach, the ultimate goal of this project is to produce spin squeezing of the ground state of an atomic cesium vapor. Success in this experiment is both of fundamental interest, in that squeezing (e.g. "beating" the Heisenberg Limit) has never been achieved in a macroscopic quantum system, and of high practical interest in the improvement of the cesium atomic clock - the very definition of time. Techniques in these experiments include ultra-low noise electronics and shot-noise limited measurement, diode lasers and diode laser stabilization, and advanced optical polarimetry.

Theoretical Quantum and Nonlinear Optics (Eberly) Professor Eberly's REU projects are focused on adiabatic and quasi-adiabatic laser-driven electronic processes in atoms. REU students learn about the field of quantum and nonlinear optics through hands-on participation in numerical simulations. Professor Eberly's previous experience with undergraduates predicts a high level of enthusiasm for this method of participation in research. Spontaneous use by undergraduates of the computers typically continues after the summer period, during the academic year. This is especially encouraged as a method of retaining contact between the student and the research group and promoting interest in physical science as a career choice.s.

b.2. 3. Projects in Medical Optics (*Foster*)

Foster's projects deal with the physics of an emerging therapy known as photodynamic therapy (PDT), optical spectroscopy of tissue and confocal fluorescence microscopy. Professor Foster is a physicist with wide experience in medical applications of physics, having worked for several years in the field of magnetic resonance imaging before becoming involved with light interactions. His program is primarily experimental but includes a significant theory and mathematical modeling component.

Physical Aspects of Photodynamic Therapy, Tissue Spectroscopy and Confocal Microscopy (*Foster)*. Photodynamic therapy involves a complex set of interactions among the treatment light, the photosensitizing agent, and oxygen dissolved in the tissue. The chemical photosensitizing agent has minimal side effects, and the radiation is highly specific laser light, whose sole function is to initiate a destructive photochemical reaction in the target tissue. Our research is focused on the essential role of oxygen supply to the tissues as measured and as calculated on the basis of the nonlinear kinetics involved. An aspect of the research has focused on developing and evaluating optical spectroscopic methods for monitoring the photosensitizer fluorescence and the tissue blood oxygen levels non-invasively in various laboratory tumor model systems. In another project, a laser-scanning confocal fluorescence microscope has been constructed and characterized. This microscope is capable of recording thin optical sections through intact solid aggregates of tumor cells, thereby making it possible to study photobleaching kinetics and other processes in a complex scattering environment. Future projects for undergraduates include (a) in vivo fluorescence kinetics of photosensitizing dyes used in photodynamic therapy of cancer; (b) confocal fluorescence imaging in tumor spheroids and tissue sections, and (c) reflectance spectroscopy of tumor oxygenation status.