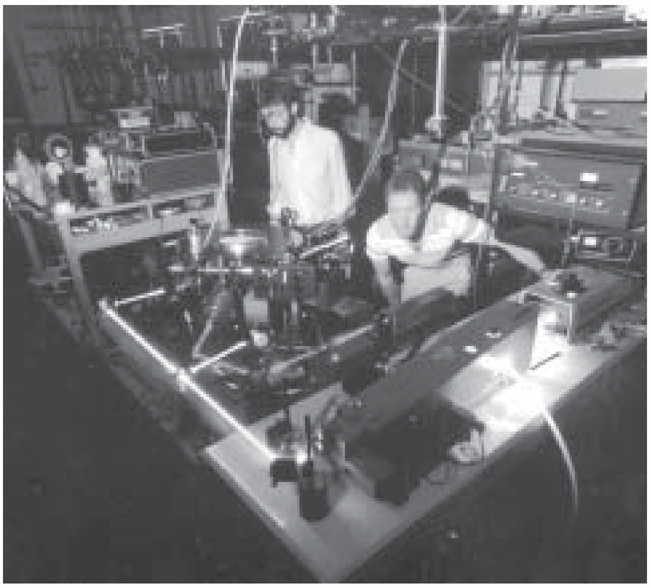
Laser Physics Centre

The Laser Physics Centre was established in the School in 1987 as the result of the amalgamation of two existing School pursuits, together with the establishment of a new laser-based laboratory. In addition, the historical cross-campus links with the laser activities of the Department of Physics in the Faculties provided an added dimension to the Centre. The result was a synergistic grouping of laser physics activities founded on a wide range of complementary laser facilities, thereby creating one of the largest laboratories of this type in the country.

The Laser Physics Centre had an initial complement of 24 in the School: four tenured academic staff members, four non-tenured staff, two postdoctoral fellows, five students, eight technical staff and one administrator. By 1995, this had grown to 43, mainly through a large increase in the number of students (to 17) and visiting staff members. Dr Barry Luther-Davies was founding Head of Department, and in 1993 was promoted to Professor.

The inaugural activities of the Centre comprised the following fields: Laser Matter Interactions (under Dr Barry Luther-Davies) - a continuation of the high power laser program in the former Department of Engineering Physics; Solid State Laser Spectroscopy (under Dr Neil Manson) - representing the laser based activites of the former Department of Solid State Physics; the UV Laser Physics Laboratory (under Dr Ken Baldwin) - a new pursuit growing out of the former molecular spectroscopy activities of the Atomic and Molecular Physics Laboratories; with Laser Diagnostics and Quantum Optics (under Prof John Sandeman and Dr Hans-A.Bachor) representing the laser activities in the Faculties.



∆ *The configuration used to perform the first atom optics experiment in Australia - the reflection of sodium atoms from a standing evanescent wave. Joe Hajnal (University of Melbourne) is on the left and Ken Baldwin at the right (1988).*

The research profile of the Centre has since evolved over the first 10 years of its existence in line with changing research directions and the School's strategic plan. The Laser Matter Interaction pursuit has gradually been wound down, and since 1991 emphasis has switched to the Nonlinear Optics program (under Prof Luther Davies and Dr Marek Samoc) which is aimed primarily at the development of new nonlinear materials for photonics applications (this project has continued under an ANU Strategic Development Grant from 1995). The Quantum Optics program in the Faculties grew and now includes work on optical detection of gravitational waves (under Dr David McClelland and Prof Sandeman). A new Atom Manipulation Project was funded under an ANU Strategic Development Grant in 1994 as a joint program in the School between the Laser Physics Centre (Dr Baldwin) and the Atomic and Molecular Physics Laboratories (Dr Stephen Buckman), in collaboration with the Atom Optics program in the Faculties (Dr Craig Savage and Prof Bachor, who for 4 years held a joint appointment in the School). This project is aimed at using laser light forces to create the equivalent of optical elements for atoms, with applications to lithography and atomic scattering experiments.

The scientific profile of the Laser Physics Centre is set out below under these pursuit headings, with highlights of the major scientific achievements.

LASER MATTER INTERACTION STUDIES

Laser-produced plasmas were studied both for their relevance to inertial confinement fusion; as sources of x-ray radiation; and for the basic nonlinear science they reveal. Short pulses of high intensity radiation from a neodymium glass laser were used to create high temperature plasmas with lifetimes in the picosecond to nanosecond scale by irradiating solid targets. Because of the high light intensities involved and the host of complex interacting nonlinear processes that can occur, laser produced plasmas offer a unique challenge to the experimental physicist. This is reflected in the need to develop diagnostics capable of resolving the complex processes which occur in these microscopic plasmas.

Apart from the host of physics results that were

Foundation members of the Laser Physics Centre (1987).

1. *Phil Chapple (Faculties)*
2. *Peter Fisk*
3. *Ken Baldwin*
4. *Bobba Vukovic*
5. *Keith Holliday*
6. *Arther Maddever*
7. *Denis Bullock*
8. *Kay Scott*
9. *Hans Bachor (Faculties)*
10. *John Sandeman (Faculties)*
11. *John Carlton*
12. *Gino Sampietro*
13. *Ranco Dragila*
14. *Barry Luther-Davies*
15. *Neil Manson*
16. *John Remmel*
17. *Robert Danby*
18. *Wally Hopkinson*
19. *Ian McRae*
20. *Keith Jackman*

obtained the research group contributed significantly to novel diagnostics for high temperature plasmas. Of the diagnostics developed in the laboratory, one which was particularly pleasing was the penumbral imaging system which was developed to image hard x-ray emission from the laser irradiated targets. This simple extension of the primitive pin-hole camera (formed by simply drilling out the pin-hole so that it was much larger than the object to be imaged) was shown to be such an effective method of coded aperture imaging, that it was adopted by the fusion program at the Lawrence Livermore National Laboratory in the USA and used to obtain the first images of a thermonuclear fusion reaction occurring in a laser heated pellet. The original ANU work carried out by Keith Nugent (then a PhD student) and Barry Luther-Davies, led to close involvement of Dr Nugent with the Livermore work and his sharing a prestigious IR100 award with the Livermore team.

Nonlinear Optics

Research in nonlinear optics covers a wide range of second and third order nonlinear optical phenomena, including photorefractive effects. In the case of second order nonlinearities, we are studying optical parametric generators as short pulse, high power frequency-tunable sources of coherent light; our work on third order phenomena range from the theory and modeling of spatial solitons, to the use of third order processes to generate short pulses of high-power laser radiation; and the development of organic materials with large third-order nonlinearities for photonics. The work is increasingly undertaken in collaboration with other groups in the University, most notably with the optoelectronic programs in the department of Electronic Materials Engineering.

Highlights include -

- pioneering studies of dark spatial solitons for use in the generation of reconfigurable optical “circuits” for photonics
- experimental demonstrations of spatial soliton creation and their interactions from 3-dimensional beams containing optical vortices
- the development of highly nonlinear materials with potential for all-optical switching
- observation of spatial soliton interactions in photorefractive nonlinear materials
- the development of range of novel photorefractive oscillators for phase conjugation and other applications

Solid State Laser Spectroscopy

The interest in the Solid State area of the Laser Physics Centre is centred round high resolution lasers and the work started in association with studies of a new method of storing digital infomation on an optical disc. The technique involves bleaching a band of colour out of a material, usually termed spectral holeburning. The narrower this band of colour, the higher the total number of bits that can be stored at a single spot, and hence the requirement of high resolution. In 1994 after the development of a kHz resolution laser, the group established the narrowest optical line ever achieved in a solid. This was clearly the highlight, but the group has established an outstanding reputation for exploring and explaining the underlying physical processes associated with holeburning using a wide variety of materials, including many grown in the Laser Physics Centre.

The group has also adopted various double resonance techniques using two laser fields, or one laser field and one R.F. or microwave field. In one such case, a defect centre in diamond was identified where, unlike most solids, the random strain within the crystal does not cause a variation in the resonance frequencies. The system then behaves much more like a isolated atom than any centre in a solid. Signals can be detected with phenomenal sensitivity, and this has led to numerous studies of two- and three-level atoms. Many of the fundamental effects associated with a driven atom, underpinning most non-linear optics, has been studied with greater clarity than has been observed previously and many

Δ *Talking on the laser light telephone, from L to R, Kylie Waring, Stephanie Cheylan, Tim Dyke, Andrew Greentree and Neil Manson (1996).*

new effects demonstrated. The crystal has proved to be a diamond mine for postgraduate students with up to six students working on the topic.

ULTRAVIOLET LASER PHYSICS

The UV Laser Physics Laboratory has two complementary experimental research programs based around a high power, pulsed dye laser facility: (1) studies of fundamental nonlinear optical processes, in collaboration with the Quantum Optics group in the Faculties (Prof Hans Bachor) (2) the application of these techniques to the high resolution VUV spectroscopy of atmospheric molecules, in collaboration with the UV Physics Unit in AMPL (Dr Brenton Lewis and Dr Stephen Gibson).

The nonlinear optics studies have centred on the generation of several multiphoton excitation pathways in atomic systems (mainly sodium), which interfere quantum mechanically to produce both constructive and destructive effects. These interferences can be used to enhance or diminish the nonlinear process being monitored, such as four wave mixing or multiphoton ionisation. Highlights include -

- the demonstration of interference between different four wave mixing processes using separate bound state resonances, in which the sign and magnitude of the interference could be controlled by varying the laser detuning from resonance
- experimental investigation of laser induced continuum structures
- the suppression of the AC Stark effect in two-photon resonant, three-photon ionisation, caused by the introduction of a second laser field which generates a competing four wave mixing pathway

One ouput of these nonlinear processes - the generation of narrowband, tunable radiation in the vacuum ultraviolet (VUV) spectrum - has been applied to the high resolution spectroscopic study of atmospheric molecules, primarily diatomic oxygen. Highlights include -

- the use of stimulated Raman scattering, third harmonic generation, and four wave mixing to carry out the highest resolution studies of photoabsorption cross-sections for oxygen in the VUV
- the observation of rotational edges and shape resonances near the oxygen Schumann-Runge continuum
- the first characterisation of isotopic differences in highly resolved rovibrational structure in O_2
- the discovery of two new states of oxygen

ATOM OPTICS

Studies in the field of atom optics - the equivalent of light optics for matter - have been performed both under an ANU Strategic Development Fund grant held in the School - the Atom Manipulation Project - and via collaborations with theorists and an ARC funded experimental project on Atomic Beamsplitters in the Physics Department, The Faculties.

The Atom Manipulation Project has as its aim the development of a bright source of helium metastable atoms using diode laser light forces to collimate, cool and focus the flux from a conventional nozzle discharge. The intense, well collimated beam of metastable helium atoms will then be used to develop massively parallel surface lithography techniques using mask technology, and also direct write techniques using hollow optical fibre atomic waveguides. The high density source will also make possible electron-atom and atom-atom scattering experiments with high sensitivity.

The Atomic Beamsplitter project had its origins in studies of diffraction of a thermal atomic beam from an evanescent light grating initially carried out in the School in 1988. The availability of dye lasers has since seen this work re-established in the Faculties, where it has progressed to the development of a cold caesium fountain based on diode laser technology.

Highlights of these programs include -

- the demonstration of reflection from an evanescent atomic mirror and the interaction of an atomic beam with a moving evanescent grating
- the realisation of a variable focal length lens for atoms
- the achievement of near-recoil transverse temperatures in an atomic beam using laser polarisation gradient cooling
- explanation of atomic diffraction from evanescent gratings using a multilevel atomic model
- a reliable caesium atomic fountain delivering cold atomic samples with velocities below 1 m/s

Ken Baldwin