Atomic & Molecular Physics Laboratories

Professor Brenton Lewis
Head of Atomic & Molecular Physics Laboratories

Atomic, molecular and optical physics is both a fundamental and enabling science that supports many other important areas of science and technology. Staff of these Laboratories pursue a broad spectrum of experimental and theoretical research into the structure of atoms, molecules, and solids, and their interactions with electrons, positrons, and photons.

http://wwwrsphysse.anu.edu.au/ampl

Research Summary

As recognised by the Division of Atomic, Molecular, and Optical (AMO) Physics of the American Physical Society, "AMO physics is an enabling science that supports many other important areas of science and technology." Indeed, students graduating in AMO physics acquire a breadth of knowledge and skills, enabling them to contribute to many areas of science, technology, and society. AMO physicists have also appeared prominently among Nobel laureates in recent times. The Atomic and Molecular Physics Laboratories are engaged in a broad range of experimental and theoretical studies of the interaction of electrons, positrons, and photons with atoms, molecules, and solids, in order both to further our knowledge of fundamental physical and chemical processes, and to provide essential information that is critical to applications in other scientific disciplines, technology, and the environment.

There has been greater stability in the Departmental structure this year. Professor Erich Weigold retired in October as School Director and now occupies the special position of PostDirectorial Fellow in the Department. We thank him for his guidance as Director and look forward, as he is, to a period of relaxing, but productive, research. During the year, Professors Robert Robson and Erich Weigold both completed their duties as Humbolt Fellows in Germany. The Department also welcomed Professor Harald Friedrich as a Visiting Fellow (jointly with the Department of Theoretical Physics [TP]), together with two new research students, Ivan Blajer and Milica Jelisavcic. In addition, we hosted six Winter and Summer Scholars who were involved in brief research projects. Congratulations are also in order for Brenton Lewis, who was promoted to Professor, and Maarten Vos and Julian Lower, who were promoted to Senior Fellow and Fellow, respectively. Finally, construction started this year on the new building wing which will house most of the Department's experimental laboratories after 2003. Together with the concurrent refurbishment of the East Cockcroft wing, this important development will serve to consolidate Departmental staff and activities, currently in disparate locations, into a single area. We look forward to the improved intra-Departmental interactions likely to result from this development.

Members of the Department were again successful in winning grants, awards, and other marks of distinction during the year. The grant success has been particularly significant to the future of the Department, considering that this has been the first year of the Institute's full eligibility for Australian Research Council grants. The Department won four grants in the ARC Discovery round, resulting in funding on the order of $500,000 p.a. The successful proposers included Professors Steve Buckman and Erich Weigold, and Drs Andrew Truscott, Julian Lower, Maarten Vos, and Anatoli Kheifets. Professor Buckman was outstandingly successful, winning two Discovery and two Linkage grants at a success rate of 100%! Toward the year's end, the ANU was successful in obtaining ARC funding for a Centre of Excellence in Quantum Atom Optics. The Department shared in this success, through the efforts of Dr Andrew Truscott and Dr Ken Baldwin (Laser Physics Centre [LPC]), obtaining funding on the order of $300,000 p.a. which will enable the pursuit of a major new project in the area of Bose-Einstein condensates, together with other collateral support. Professors Brenton Lewis and Bob McEachran, together with Drs Steve Gibson, Anatoli Kheifets, Jim Mitroy (Northern Territory University), and members of other departments, were also successful in obtaining Major Equipment Committee funding for a fast workstation to enable the simultaneous interactive pursuit of computer-intensive theoretical research projects. The second tranche of Institute Planning Committee funding was received by the School during the year, partly for the appointment of an atmospheric modeller to the Solar-Terrestrial Environmental Programme (STEP) of the Department. Dr Frank Mills, of the Jet Propulsion Laboratory, Los Angeles, has been appointed to this position, held jointly with the Centre for Resource and Environmental Studies, and is due to start in 2003.

Finally, during the year, Professor Bob Crompton was greatly honoured to have been made an Honorary Fellow of the Australian Institute of Physics, Professor Brenton Lewis was elected to Fellowship of the Optical Society of America, Colin Dedman was awarded

Professor Lewis Chadderton honoured by the International Nuclear Track Society - Jubilee Congress, New Delhi, November 2002

a Council Medal for general-staff excellence, Professor Lewis Chadderton was awarded Honorary Membership of the International Nuclear Track Society, and Dr Steve Gibson was elected to Council of the Australian Optical Society. Dr Anatoli Kheifets was again honoured by the holding of the second Anatoli Kheifets Workshop on Atomic Photoionisation in Japan.

The international profile of the Department remains strong, as evidenced not only by continuing receipt of international awards and learned-society fellowships, but also by 13 invitations to speak at mainly international conferences, and an ongoing commitment to 35 collaborative projects, most involving international collaborators. Of approximately 50 refereed Departmental publications this year, nearly two-thirds have international coauthors.

A brief summary of the research activities in the Department is given below. Those readers requiring further details should view the projects listed in Section 3 under Collaborative Ventures, and/or download manuscripts for the publications listed in Section 5. Details of some of the collaborative projects of AMPL staff members may also be found in the LPC and TP reports. In the broadest sense, the Departmental research activities in AMO physics, both experimental and theoretical, may be classified principally under three headings (although there is some cross-fertilisation): atom manipulation, electron impact (including positrons), and photon impact.

Atom Manipulation

The Atom Manipulation Project is a joint program between AMPL and the LPC which uses laser cooling and trapping techniques for atom-optics and atomic collision experiments. Activities this year have centred on improvements to the metastable He atom trap and theoretical modelling of soliton trains formed in a quasi one-dimensional Li Bose-Einstein Condensate (BEC). A new activity, the creation of a metastable He BEC, will be established by Dr Truscott, following the award of ARC Centre of Excellence funding for the Centre for Quantum Atom Optics.

Electron Impact

Low-Energy Electron Scattering from Atoms and Molecules

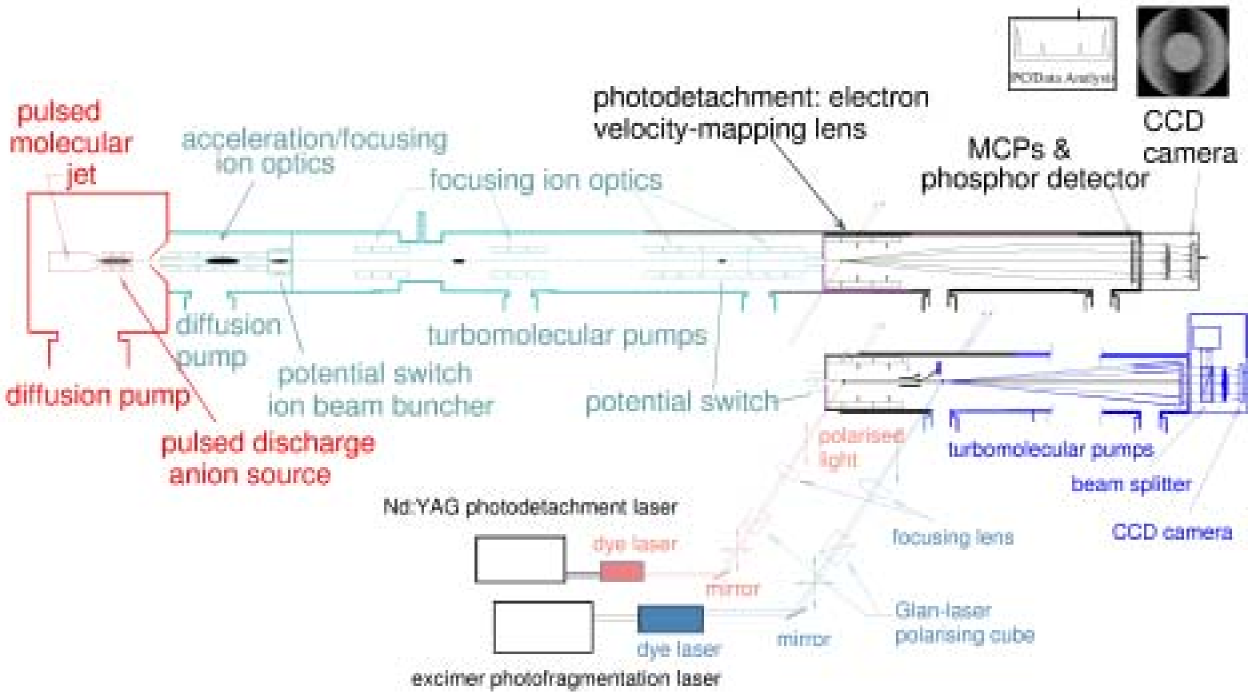
Following a major overhaul of the crossed-beam apparatus in the early part of the year, measurements of differential cross sections and excitation functions for ethylene have been completed and a series of measurements on very-low-energy electron scattering from nitric oxide have commenced. Both molecules are of fundamental and environmental interest, especially at low impact energies. A major review article on electron-molecule scattering cross sections by Brunger and Buckman was published in 2002 in Physics Reports.

Electron Scattering from Metastable Helium

Progress has been slow on the measurements of absolute total scattering cross sections from trapped metastable He (2^3S). The main problem has been maintaining sufficient atom density in the trap after the trapping fields are turned off. Several schemes, including optical molasses and atom release and recapture are being investigated in order to overcome this problem.

Quantum-State-Resolved Electron-Impact Ionisation

In this experimental program, kinematically-complete (e,2e) coincidence techniques, in conjunction with spin-resolved beams of electrons and target atoms, are used to obtain detailed



Schematic Diagram of the photofragment spectrometer

knowledge of the process of electron-impact ionisation, thus sensitively probing the many-body behaviour of groups of interacting electrons, the understanding of which is central to the description of a wide range of physical phenomena. Significant developments in instrumentation have occurred this year. Our double-toroidal spectrometer, which simultaneously detects two electrons over large ranges of scattering angles and energy, can now accurately measure weak processes, such as simultaneous ionisation and excitation, at the 0.1% level. In addition, the feasibility of triple-coincidence measurements has been demonstrated.

Electron-Momentum Spectroscopy (EMS) of Solids

EMS measurements of ultra-thin single-crystal silicon have revealed details of the anisotropic electronic structure, as well as a wealth of diffraction effects, and are likely to provide a great test case for many-body perturbation theories. Construction of a new electron-beam evaporator has made the study of a large variety of metals possible, leading to new insights into the energy-resolved momentum densities of iron, nickel, and copper. Construction of a polarised electron source, which will enable the study of magnetic films by EMS, is well underway. Finally, our theory of electron correlation in solids has been tested in a series of local experiments. In particular, theoretical results on light *s, p* elemental solids have been confirmed experimentally.

Elastic Scattering from Hydrogen in Solids

Both electron and neutron scattering studies provide information on the momentum distribution of hydrogen in materials, but there are inconsistencies between results provided by the two techniques. Beam time has been awarded at ISIS, the world's leading facility for the production of neutrons, for a comparative study of neutron and electron scattering from nuclei, with a view to solving this puzzle.

Multiple Atomic Ionisation

The theory of multiple atomic ionisation has been further developed to include low-energy electron impact, complex atomic targets, and simple diatomic molecules. Experiments at the Max Planck Institute for Nuclear Physics, Heidelberg, and the Photon Factory, Tsukuba, have confirmed key predictions of the theory.

Electron-Impact Excitation and Ionisation of Atoms

The calculation of accurate triple differential cross sections for inner-shell ionisation of atoms remains a challenge. The role which exchange plays in these ionisation processes has been investigated and significantly improved agreement with experiment obtained. Fully relativistic calculations of atomic excitation cross sections and spin-dependent parameters have proved successful, but it is desirable to extend this method through second order.

Positron-Impact Excitation and Ionisation of Atoms

Following improvements in the energy resolution and intensity of positron beams, the first cross section measurements of the first two fine-structure levels of Ar have become available. Relativistic distorted-wave calculations of these cross sections have been carried out and satisfactory agreement with experiment obtained. However, it is clear that positronium formation needs to be incorporated into these calculations, as well as those for ionisation.

Momentum-Transfer Cross Section for Mercury

Accurate low-energy cross sections for electrons in mercury vapour are needed for modelling mercury discharges in lighting devices. The first theoretical calculation to substantially agree with the experimental low-energy momentum transfer cross section have been performed. Because of the toxic nature of mercury, zinc is currently being investigated as a replacement in lighting devices. Thus, similar calculations of the total and momentum transfer cross section are being extended to zinc.

Electron-Hydrogen Vibrational Excitation

The suitability of the semi-classical Boltzmann collision operator for describing electron-molecule collisions involving rotational and rovibrational excitation continues to be investigated, in order to resolve the well-known and long-standing swarm experiment-quantum theory-beam experiment stalemate for electron-hydrogen scattering.

Negative Mobilities and the Second Law

Recent theoretical predictions of negative mobilities seem to imply Joule "cooling" and violation of the Second Law of Thermodynamics, but closer investigation through non-equilibrium thermodynamics reveals that total entropy production is indeed positive, and the Second Law remains intact. However, the same analysis shows that traditional swarm experiments will never be able to observe such negative mobility phenomena, as these experiments measure the "bulk" drift velocity, which is always positive.

Non-Hydrodynamic Transport Phenomena

The modern study of transport phenomena in ionised gases is chiefly motivated by the need to understand the behaviour of low-temperature plasmas in the neighbourhood of sources and boundaries where gradients may be large and distinctly non-hydrodynamic conditions prevail. These problems are of fundamental physical interest and are being investigated through

Photon Impact

Vacuum Ultraviolet (VUV) Laser Spectroscopy (jointly with the LPC, incorporating the STEP)

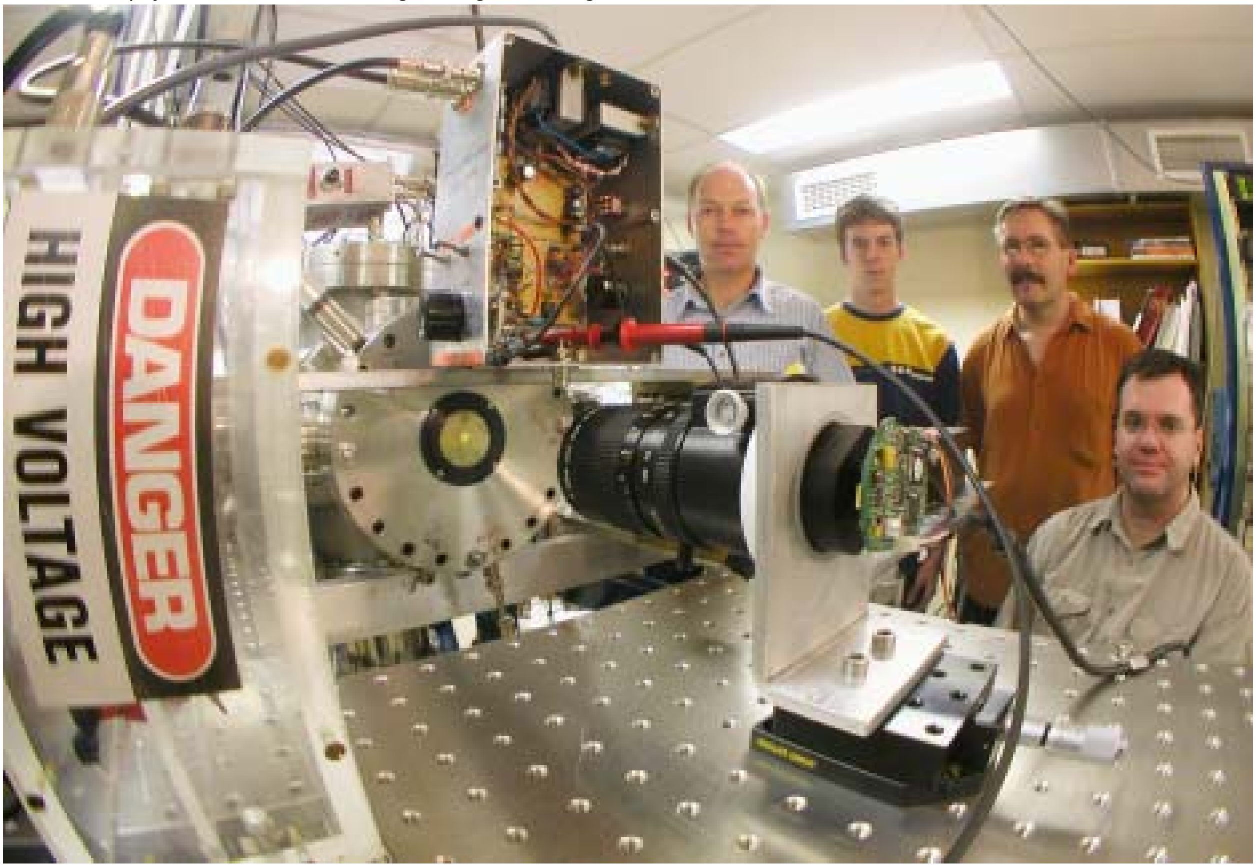
The work under this program is aimed at developing and applying high-resolution widely-tunable, coherent sources of VUV radiation to studies of the structure and photodissociation dynamics of molecules of atmospheric and environmental interest. Activities this year have centred on the development and characterisation of a new, high-resolution, pulsed laser source based on a periodically-poled KTP crystal in a ring-cavity optical parametric oscillator (a joint ARC project with Macquarie University), together with the first laboratory measurements to demonstrate quantum-interference effects in the Schumann-Runge band spectrum of molecular oxygen.

Photodetachment and Photofragment Spectroscopy

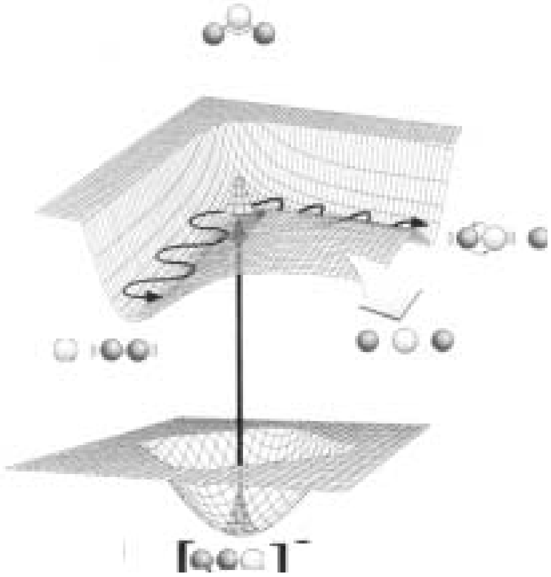
Good progress has been made on the construction of the fast-beam photodetachment and photofragment spectrometer, despite several long delays associated with equipment failure. A new electron imaging system for photodetachment spectroscopy (Velocity Map Imaging) has been implemented, enabling the simultaneous acquisition of high-resolution photoelectron spectra and full angular distributions. The first data, on molecular oxygen, are expected in 2003.

Close-Coupled (CC) Spectroscopy

In this computational program, the techniques of scattering theory are applied to the "half-collision" process of molecular photodissociation, CC procedures allowing the treatment of complex interactions between the molecular excited states. This



The photofragment spectrometer with some usual suspects year, there has been further development of a model of molecular oxygen photodissociation, with applications in the field of terrestrial-atmospheric photochemistry, together with the first steps towards the construction of a CC model of molecular nitrogen photodissociation in the extreme ultraviolet, with applications in the interpretation of NASA-mission data from past and future planetary encounters with, e.g., Titan, Triton, and Pluto. An essential aspect of the CC model development involves the analysis and interpretation of experimental data from a number of international laboratories, e.g., SRI International (San Francisco), Edinburgh University, and Vrije Universiteit (Amsterdam), giving a strong international collaborative flavour to the CC program.

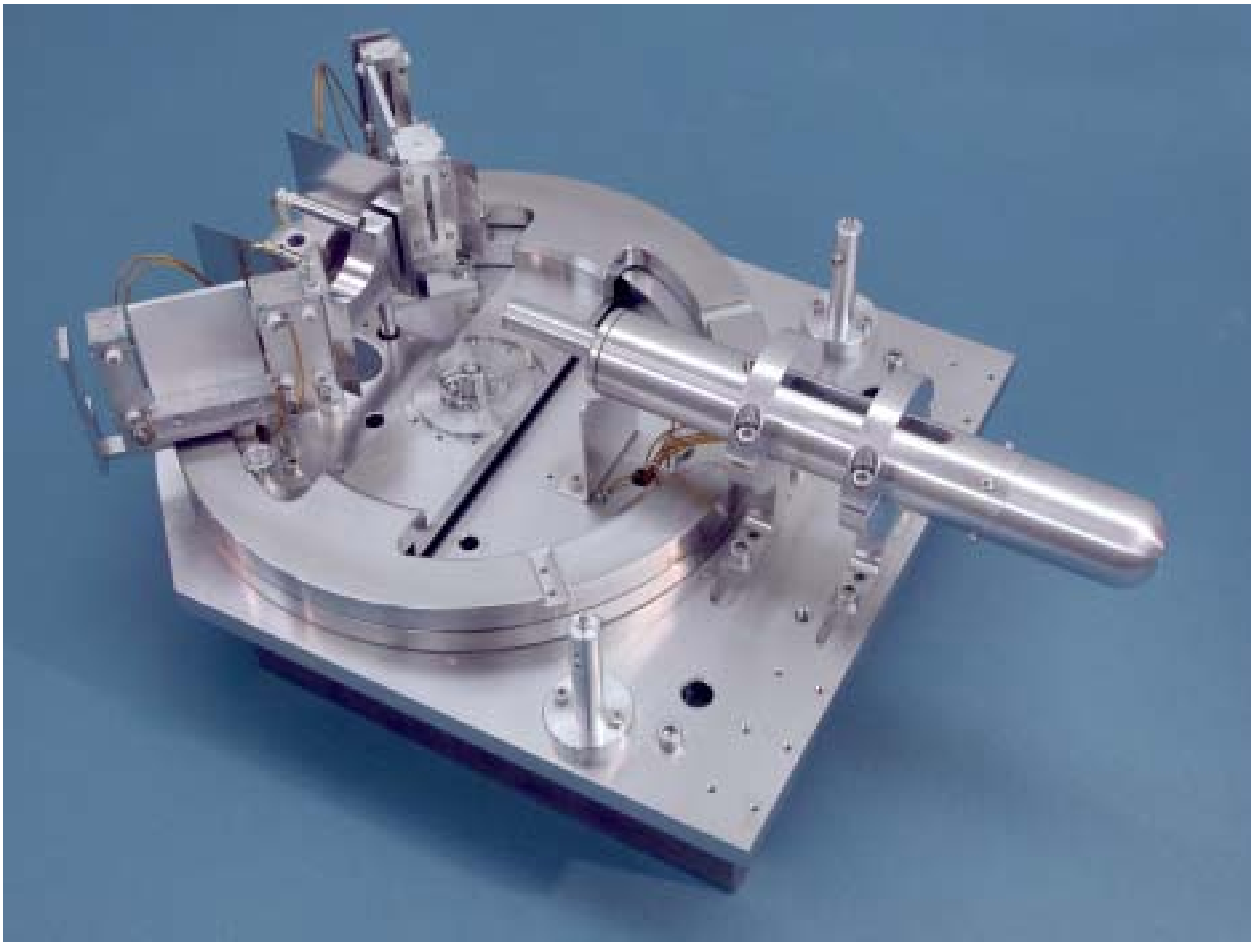


Transition state spectroscopy is studied using the coincidence photofragment/photodetachment spectrometer. The stable negative ion accesses the unstable (transient) neutral species, opening a window into the intermediate zone between reagents and products of chemical reactions

Other Areas

Nanostructure of Opal

Opal consists of spheroids of silica gel, about a quarter of a micron in diameter, arrayed periodically. This period, which is comparable to the wavelength of visible light, gives rise to the optical bandgap effects that give opal its characteristic lustre. Investigations have been made by Atomic Force Microscopy of the cleavage structure of opal. The nuclei of the spheroids, a few nm in size, are found to behave mechanically in a way different from the bulk. The composition of opal, particularly of the nuclei, is being investigated by chemical and nuclear analysis.



Collimating optics, deflectors and Faraday cup from the Electron - Momentum - Spectroscopy of Solids apparatus

Staff and students of the Atomic and Molecular Physics Laboratories 2002

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