Theory Cluster

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The Theory Cluster comprises the Department of Theoretical Physics, the Nonlinear Physics Group, the Applied Photonics Group and the Optical Science Centre. Each group has its own head of department and each group is independently administered.

Department of Theoretical Physics

Research Summary

The study of physics involves the discovery of quantitative laws of nature. The challenge for theoretical physics is to unravel these laws and to elucidate their consequences. The research in the Department covers a broad spectrum of activities including atomic and molecular physics, biophysics, condensed matter physics, nuclear physics, plasma physics and statistical mechanics and field theory.

The Department continued its success in the ARC Discovery program. In addition to the large grants in the area of statistical mechanics and field theory awarded for 2002–2004 to Professors Bazhanov and Baxter, Professor Batchelor was awarded $1.1 million for 2003–2007, including an Australian Professorial Fellowship. In biophysics, Dr Chung was awarded $1 million for 2002–2004 for research on biological ion channels. Other new grants for 2003–2005 include $600,000 to Dr Ball, Professor Dewar and Dr J. Frederiksen (CSIRO) in plasma physics and $300,000 to Dr Kheifets, jointly with Dr Vos and Professor Weigold (AMPL), in electron momentum spectroscopy.

The Department is host to the Centre for Complex Systems (CCS). The Centre's activities are highlighted elsewhere.

Atomic and Molecular Physics

Ultrafast Coherent Dynamics of Localised Modes in Many-Body Systems

The use of femtosecond laser pulses is a celebrated tool for the real-time monitoring of ultrafast coherent molecular dynamics, important, e.g., for environmental science and biology. This method is restricted to unimolecular reactions only. It was shown that the bimolecular collision experiments with pure energy resolution can provide information on the reaction dynamics equivalent to that obtained using standard femtochemistry methods. This allows the study of ultrafast coherent dynamics of localised modes, e.g., in heavy-ion collisions, electron-molecular scattering, atomic cluster collisions and electron scattering from nanostructures. It was demonstrated that in some instances the method provides time resolution of six orders of magnitude better than conventional methods of femtochemistry. Some projects have been carried out in collaboration with AMPL.

Many-Body Localised Modes and Nonergodic Molecules in Continuum

Very strong sensitivity of the cross section energy autocorrelation functions to the relaxation time of localised modes excited in microscopic and mesoscopic collisions has been demonstrated. The extremely stable many-body localised modes in nuclear molecules confirm an earlier prediction that the dephasing can be much slower than the intramolecular energy redistribution, with these modes surviving a thermalisation of the highly excited many-body system. The localised modes result from coherent superpositions of a very large number of strongly overlapping many-body molecular resonances producing unusual states — nonergodic molecules in continuum. Anomalously long dephasing times observed in highly excited polyatomic molecules may reflect this new type of nonergodicity.

Biophysics

There is a great deal of diversity among the potassium channels observed in nature. Their conductance levels vary by almost two orders of magnitude yet they all exhibit the same selectivity against sodium ions. The latter property is explained by the fact that the structure of the selectivity filter found in the KcsA potassium channel is conserved among all the potassium channels. But the observed KcsA structure sheds little light on the diversity problem. To investigate this problem, a model was constructed with potassium channels having similar structures to KcsA but differing in their intra-pore radius. Electrostatic calculations of the multi-ion potential energy profiles revealed that the central energy barrier decreases with increasing intra-pore radius. This leads to an exponential increase in channel currents as confirmed by Brownian dynamics (BD) simulations. Thus the large variations in conductance of potassium channels are understood in terms of structural changes in the intracellular side of the protein that is known to differ widely among the potassium channels.

Work on gramicidin channel continued with the emphasis shifted from continuum electrostatics, which was shown to break down previously, to deriving the potential of mean force (PMF) of ions in the channel using molecular dynamics simulations. The PMF profiles obtained using the two popular force fields (GROMACS and CHARMM) yielded large central barriers exceeding 20 kT. This translates to a drastic suppression of channel current incompatible with the experimental observations. The most likely reason for the failure of these force fields is the neglect of the induced polarisation interaction. Work is in progress to include the polarisation effects explicitly in the PMF calculations. A positive result will have far reaching implications for applications of MD simulations to ion channels and other biological systems.

Condensed Matter Physics

Density Functional Theory of Super-Phenomena

Density functional theory is considered as a standard method for studying low energy physics, delivering very impressive results in the study of the normal state of matter. However, experience shows that at low enough temperature the lowest energy state of a many-body quantum system is not really a normal state. Inter-particle correlations in conjunction with statistics connive to form condensates, which exhibit super-phenomena (superconductivity and superfluidity). The occurrence of Fermi and Bose condensates is being studied in the realm of density functionals as fundamental processes. The aim is to obtain a pairing potential that sustains an order parameter due to broken symmetry. At the Hartree mean-field level this theory has produced the well known BCS results. An examination of the adiabatic connection formula is underway.

Mesoscopic Systems and Organic Superconductors

Charge conduction and current noise are intertwined phenomena. A unified description of both quantised conductance and nonequilibrium thermal noise in a one-dimensional ballistic wire, open to macroscopic leads, has been given. While four-terminal measurements in such a conductor give evidence of resistance-free charge transport, its two-terminal resistance exhibits finite universally scaled quantised steps. At the two-probe conductance steps, the excess noise of field-excited ballistic carriers displays sharp peaks much larger than for shot noise. The thermal noise peaks are dramatically sensitive to the inelastic scattering effects in the leads that degrade universal conductance scaling. Thus, high current thermal noise yields unique clues to the origin of contact resistance and the crossover to diffusive conduction.

Transport of charge carriers can be controlled by doping through chemical and physical means. Unlike chemical doping, physical doping is carried out by a special technique through gate voltages in field effect transistor geometry. This technique keeps the carrier channels free from defects without complications from the crystalline structure and the doping density. The occurrence of superconductivity on the interface of a device by an unconventional technique has been studied and a dynamical pairing mechanism governed by the excitons in the active device examined. The pairing of charge carriers takes place when the system is in a nonequilibrium (driven) state. The physics of a plausible superconducting transition has been discussed and new experiments suggested.

Interaction between Semiconductor Nanostructures and Intense Terahertz Laser Fields

The effects of intense terahertz laser radiation on transport and optical properties of semiconductor nanostructures in the presence of quantising magnetic fields have been studied in conjunction with experimental measurements. A theoretical approach has been developed to calculate magneto-transport and magneto-optical coefficients of low-dimensional electron gas systems when a linearly polarised intense laser field (provided by FELIX free-electron laser in Europe) is present.

The effects of intense terahertz laser radiation on hydrogen-like impurities in semiconductor systems have also been studied. A theoretical model has been developed to calculate laser-dressed binding energies and transition energies, with the results obtained from this study to provide a theoretical background for further experimental investigations.

Strong Electronic Correlations and High-Tc Superconductivity

The comprehensive investigation continues into the properties of magnetically ordered phases which appear in one- and two-dimensional strongly correlated systems, using the non-Abelian density matrix renormalisation group developed last year. In one dimension, the properties of the ferromagnetic phases were analysed in the Kondo lattice and periodic Anderson models. In two dimensions, the stripe phase was studied in the t-J and periodic Anderson models. In low-dimensional strongly correlated electron systems the interplay of localised moments and conduction electrons was addressed using Abelian bosonisation. The double-exchange ferromagnetic interaction was studied in the periodic Anderson model. The impact of phonons on the magnetic properties of the Kondo lattice model were analysed and the phase diagram of the model determined. The effect of the localised spin dilution was also studied in the Kondo lattice model. In this case, it was discovered that dilution drives the system to antiferromagnetism.

The nature of high-temperature superconductivity remains elusive despite the many novel models that have been proposed. This problem was studied using a technique based on an infinite order unitary transformation. The transformation was successfully applied to the two and three band, two-dimensional Hubbard models containing phonons. The effective spin and charge interactions were exactly determined.

Nuclear Theory

Quantum Mechanics

It was shown that the momentum density conjugate to a bosonic quantum field splits naturally into the sum of a classical component and a non-classical component with the field and the non-classical component of the momentum density satisfying an exact uncertainty relation. This motivates a new approach to bosonic quantum fields. In particular, the postulate that an ensemble of classical fields is subject to non-classical momentum fluctuations, of a strength determined by the field uncertainty, leads from the classical to the quantum field equations. Examples include scalar, electromagnetic and gravitational fields.

Light Nuclei

Values of the electron-screening potential for various reactions between light nuclei have been obtained from fits to low-energy cross-section data. Measurements of the $^{14}N(^3He, ^6He)^{11}N$ cross section have been analysed by R-matrix formulae in terms of the six lowest levels of ^{11}N. The two-proton decay widths of the ground and first excited states of ^6Be and of the ground state of ^8C have been calculated using R-matrix formulae, and are in reasonable agreement with the experiment. The half-life of ^{45}Fe calculated using an R-matrix formula for the contribution due to diproton decay agrees with experimental values provided the available decay is near the upper limit of the experimental range. In contrast with a recent publication, the energies of the lowest $1/2^+$, T = 3/2 levels of ^{11}B and ^{11}C from potential-model and R-matrix calculations are found to be found in reasonable agreement with agreement, although there may be disagreements for the widths of these levels.

Antiproton-Deuteron Scattering

Work on fitting the experimental differential cross section for pd elastic scattering at 179.3 MeV employing the pp scattering amplitude obtained from pp scattering experiments to determine the parameters of the elementary pn scattering amplitude at 179.3 MeV has continued. The results are being compared with other analyses.

Generation Model of the Fundamental Particles

A new classification of the fundamental particles (six leptons, six quarks and their twelve antiparticles) and the twelve fundamental 'force' particles (photon, three massive weak force bosons and eight gluons) based upon the use of only three additive quantum numbers (charge, particle number, generation quantum number) compared with the nine additive quantum numbers of the Standard Model (charge, electron lepton number, muon lepton number, tau lepton number, baryon number, strangeness, charm, bottomness, topness) has been developed.

Unlike some of the additive quantum numbers of the Standard Model, the three additive quantum numbers of the new Generation Model are strictly conserved in strong, electromagnetic and weak interactions.

The Generation Model provides a new basis for the weak isospin symmetry characteristic of both leptons and quarks.

Plasma Physics

The structural properties of an economical model for a confined plasma turbulence governor were investigated through bifurcation and stability analysis.

A close relationship was demonstrated between the underlying bifurcation framework of the model and typical behaviour associated with low- to high-confinement transitions such as shear flow stabilisation of turbulence and oscillatory collective action.

In particular, the analysis evinced two types of discontinuous transition that are qualitatively distinct.

One involves classical hysteresis, governed by viscous dissipation.

The other is intrinsically oscillatory and non-hysteretic, and thus provides a model for the so-called dithering transitions that are frequently observed.

This metamorphosis, or transformation, of the system dynamics is an important late side-effect of symmetry-breaking, which manifests as an unusual non-symmetric transcritical bifurcation induced by a significant shear flow drive.

Fusion Theory

A model for transition to shear modes triggered in tokamaks has been proposed. This model takes into account the linear and quasilinear behaviour of the ion temperature gradient driven perturbation, considered nowadays as the dominant source of anomalous energy losses in the low confinement mode. Analytic and numerical studies showed that the sign of the second derivative of the parallel velocity with respect to the radial coordinate determines the mode selection and stability. Theoretical studies were also undertaken to explain the salient features of the RI-mode on TEXTOR-94. Among the results obtained, it was shown that the linear increase in the energy confinement time with electron density can be explained by turbulence originating from the electron temperature gradient driven modes.

Space Plasma

A fundamental reality throughout the space plasmas is the existence of magnetic field-aligned flows. It is usually believed that the spatial transverse shear in the parallel flow destabilises many low frequency instabilities and this may be the origin of low frequency oscillations in the ionosphere. It was shown that this notion of destabilising influence of the shear in the parallel flow can be changed altogether if one takes the effect of the flow curvature (second spatial derivative) into account. The transverse curvature in the parallel flow can overcome the destabilising influence of the shear and can render the low frequency modes stable. This theoretical finding seems to have been supported in the high temperature laboratory plasma experiments at STOR-M tokamak in Canada.

H-1 Theory

Recently there has been considerable interest in whether radio frequency (rf) waves can be used to create the transport barrier to reduce the loss of particles and energy from plasma. The formation of transport barriers by the rf waves, in usual wisdom, relies on the hypothesis of the generation of rf-driven flow shear and consequent suppression of turbulence. Although rf can introduce toroidal flow, the momentum transferred to the electrons from the rf field is dissipated quickly by the background ions and in reality toroidal rotation induced by rf is small. Similarly, poloidal flows have been observed in the last run of experiments in the Tokamak Fusion Test Reactor, but not of the magnitude believed to be required to obtain a barrier. An alternative way of forming transport barrier by rf waves is suggested, with the ponderomotive force induced by rf waves in the range of the Alfven frequency creating a transport barrier in a fusion device. It is shown that if the radial profile of the rf field energy is properly chosen the linear mode is stabilised and turbulent momentum transport reduces. The rf power required for this stabilisation is found to be rather modest and hence should be easily obtained in actual experiments. The relevance of this theory to the experimental data on H-1 will be investigated.

Magnetohydrodynamic (MHD) Spectral Studies

Plasmas support an enormous variety of collective motions and the study of the spectrum of the eigenmodes of oscillation is an important approach to the understanding of plasma behaviour. However, the lack of a continuous symmetry in stellarator magnetic confinement devices, such as the ANU heliac, H-1NF, makes this a challenging problem because the toroidal mode number is no longer a good quantum number and the spectrum may be "quantum chaotic". A data set of approximately 100 negative real eigenvalues of the square of the frequency in a variant configuration of the German W7X stellarator (under construction) has been computed using the ideal-MHD CAS3D code. Two statistical measures have been used for characterising the spectrum — the probability distribution for the separation of eigenvalues, and the Dyson-Mehta rigidity. Both show strong departure from the Poissonian behaviour characteristic of regular spectra in quantum systems, which may be evidence for quantum chaos.

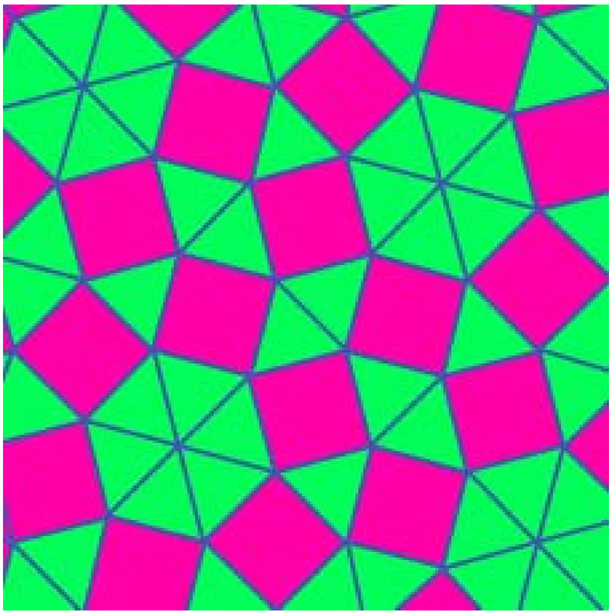
Further work on validating the incompressible resistive MHD code SPECTOR-3D has been performed, and a new compressible version has been written. Analytic studies of the spectrum in a cylindrical plasma have shed light on the effect of the incompressibility approximation on the spectrum.

Visualisation of 4D Poincare Sections

A powerful technique for the investigation of dynamical systems is the visualisation of successive intersections of orbits with a subspace (the Poincare section) of dimension one less than that of the phase space. These plots can immediately show the presence of chaos, attractors, etc., and are routinely used for two-dimensional (2D) sections. However, the advanced interactive immersive 3D visualisation capability of the ANU WEDGE technology allows the visualisation of 3D sections, or, with the use of colour coding, of 4D sections. This idea has been implemented using Java3D in the WEDGE for the Froeschle map (two coupled standard maps) and will be used to investigate criteria for the existence of KAM tori.

Statistical Mechanics and Quantum Field Theory

The revived question of the completeness of the Bethe Ansatz for the six and eight-vertex models in statistical mechanics was studied and verified for a number of typical problem cases.



A random tiling associated with a solvable lattice model in statistical mechanics

The free energy of the chiral Potts model was shown to be a meromorphic function on a particular Riemann surface with a complete description of its zeros and poles given. Such descriptions play a very useful role in exactly solvable models, and this is the first time this has been done for the chiral Potts model.

The functional equations for excited states in the massive Quantum Field Theory obtained by $\phi_{2,1}$ perturbation of the $M_{3,5}$ model of Conformal Field Theory were studied.

Investigation of the combinatorial aspects of the groundstate wavefunction of loop models continued with a series of new conjectures formulated for the rotor model. The investigation of the magnetic properties of exactly solved quantum spin ladders continued with detailed calculations given for the spin-1 ladder of relevance to the experimental compound BIP-TENO. Probabilities for random walkers to be absorbed at the ends of a number of lattice tubes, including the square, triangular and honeycomb lattices were also derived. The problem on the triangular lattice was previously considered to be intractable. These results may apply to the physics of carbon nanotubes.

Nonlinear Physics Group

Research Accomplishments

The Nonlinear Physics Group is engaged in fundamental research on nonlinear phenomena and the dynamics of nonlinear localised modes, guided waves, and solitons in various branches of physics. The interdisciplinary research of the Group covers several topics such as nonlinear effects in optical bulk media and optical fibers, all-optical switching devices, nano-optics and photonic crystals, self-trapping effects and energy transfer in condensed matter physics and biopolymers, nonlinear atom optics and matter waves including the dynamics of the Bose-Einstein condensates.

2002 was, for many reasons, a very special year for the Nonlinear Physics Group. The first international meeting of the Sir Oliphant Conference Series with over 100 participants, the first Federation Fellowship of the School, two Australian Research Council research grants, and a big share in two recently announced Australian Research Council Centers of Excellence with a total of ~$3M in research support for the next five years are just a few examples of the Group's brilliant performance and achievements in the past year. Along with the long-standing reputation of one of the most active and productive research groups in Australia, the Nonlinear Physics Group becomes one of the most successful in the Australian National University and the School in gaining external funding through the new funding scheme that was introduced last year. We believe that in the coming few years, the Group will expand substantially while playing a leading role in the two Centers of Excellence and gradually evolving into a full-size department of the School. The recent awards would also allow the Group to extend its activities into several novel research directions such as left-handed meta-materials and biophysics, as well as to amplify the quality of research in soliton physics and photonic crystals, as well as Bose-Einstein condensation.

The Group members continued research on optical solitons as part of an international research team composed of members of the Group and the Laser Physics Centre, working on both theory and experiment. These activities have been supported by the appointment of Dr Dragomir Neshev, a former Visiting Research Fellow, as a Research Fellow in a three-year position. Another Visiting Research Fellow of the Group, Dr Anton Desyatnikov, was awarded a Fellowship of the Humboldt Foundation and he is now in Münster, also keeping close contacts with the Group.

The Group plays an active role within the Institute of Advanced Studies, hosting many overseas researchers and research students. In 2002 we continued to work on several novel research directions, including the physics of photosensitive optical materials (in collaboration with the experimental team of Professor Satoshi Kawata from Osaka, Japan). An extensive review paper in the special issue of the Journal of Nonlinear Optical Physics and Materials devoted to Professor A.M. Prokhorov is a result of this extensive collaboration. Additionally, in 2002 we embarked on a new research direction, the physics of left-handed meta-materials, with our new PhD student Ilya Shadrivov as a key player.

The research interests of the Group are expanding each year, and now include areas beyond traditional nonlinear optics and soliton physics, such as linear and nonlinear propagation of light along photonic-crystal waveguides and waveguide bends, nonlinearity-induced folding and self-assembly of biopolymers, the dynamics of nonlinear matter waves, the stability of optical vortices and the dynamics of vortex matter, novel photonic materials and devices. Four distinct research streams can now be identified according to the main interest of the Group's key players: (i) nonlinear optics and optical solitons (Dr A. Sukhorukov and Dr D. Neshev); (2) nonlinear matter waves and Bose-Einstein condensates (Dr E. Ostrovskaya and Ms P. Louis); (3) photonic crystals and waveguides (Dr A. Sukhorukov and Dr S. Mingaleev); (4) left-handed meta-materials and waveguides (Mr I. Shadrivov and Dr A. Sukhorukov). These main directions are interlinked by our wide expertise in nonlinear physics, so that the Group members share many common interests across the spectrum of nonlinear physics research. One of the excellent examples of such collaboration is a number of recent projects devoted to nonlinear waves in periodic media, covered by both the physics of photonic crystals, and the theory of Bose-Einstein condensates in optical lattices.

Nonlinear Optics and Optical Solitons

One of the most important highlights of 2002 is the completion of the book "*Optical Solitons: From Fibers to Photonic Crystals*" by Yuri Kivshar and Govind Agrawal (University of Rochester, USA) which is scheduled for publication by Academic Press in March 2003. The book is the first to provide a thorough overview of different types of optical solitons and their applications. The main purpose is to present the rapidly developing field of optical solitons starting from the basic concepts of light self-focusing and self-trapping. It introduces the fundamental concepts in the theory of nonlinear waves and solitons using physically realistic models of nonlinear optics while also focusing on their stability and dynamics. In addition, it summarises a number of important experimental verifications of the basic theoretical predictions and concepts covering the observation of self-focusing in the earlier days of nonlinear optics and the most recent experimental results on spatial and temporal solitons, gap solitons, vortex solitons, discrete solitons, incoherent solitons, and solitons forming in photonic crystals, and introduces the fundamental concepts in the theory of optical solitons through realistic physical models. The material is based

Professor John Love (left) and Professor Yuri Kivshar (right) celebrate the successful year at the Christmas lunch with their colleagues and students on the authors' years of experience actively working in and researching the field, and provides links with other fields such as the nonlinear dynamics of spin waves and nonlinear matter-waves in the Bose-Einstein condensates.

The most recent activity of the Group is the investigation of the nonlinear light localisation phenomena in the periodic refractive index gratings that are optically induced in photorefractive materials. This experimental and theoretical research is conducted by Dr D. Neshev, Dr A. Sukhorukov, and Dr E. Ostrovskaya, in collaboration with Dr W. Krolikowski (Laser Physics Centre). The study of the physics of propagation and localisation of light in these reconfigurable periodic photonic structures opens up new possibilities for all-optical control and manipulation of light in nonlinear media.

Bose-Einstein Condensates

Two years ago, our Group started research in a completely new and exciting field of Bose-Einstein condensation (BEC). In collaboration with Dr C. Savage from the Faculties (ANU), the Group initiated a number of projects in this rapidly developing area of physics. More recently, the Atom Optics Laboratory in the Faculties, led by Dr J. Close, have produced the first Australian BEC which takes them a step closer to establishing a National Atom Laser Facility in future years. A number of important theoretical results have been produced in collaboration with our Group and will be tested experimentally. Our recent results in this field include the study of BEC in optical lattices. In particular, we analysed the existence and stability of spatially extended (Bloch-type) and localised states of BEC loaded into an optical lattice, and studied the band-gap structure of the matter-wave spectrum in both the linear and nonlinear regimes. We demonstrated the existence of families of spatially localised matter-wave gap solitons, and analysed their stability in different band gaps, for both repulsive and attractive atomic interactions.

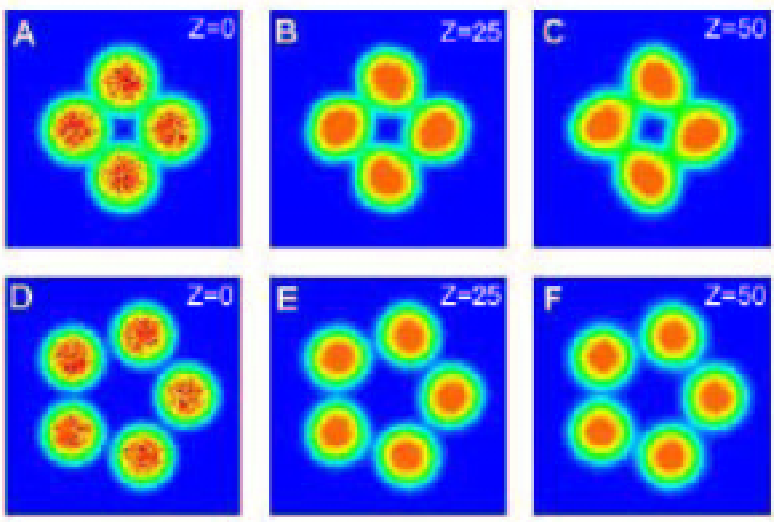
Photonic Crystals and Waveguides

One of our new areas of research continued in 2002 was the study of *nonlinear properties* of photonic crystals and photonic crystal waveguides. Photonic crystals are usually viewed as an optical analog of semiconductors that modify the properties of light, similar to a microscopic atomic lattice that creates a semiconductor band-gap for electrons. It is believed therefore that by replacing relatively slow electrons with photons as the carriers of information, the speed and band-width of advanced communication systems will be dramatically increased, with potential benefits for the telecommunications industry. However, to employ the high-technology potential of photonic crystals, it is crucially important to achieve a dynamical tunability of their properties. This idea can be realised by changing the light intensity in *nonlinear photonic crystals*. Harnessing the nonlinear properties of photonic crystals and photonic-crystal waveguides offers an opportunity to create the all-optical analogs of diodes and transistors that will one day enable the first all-optical computer to be built. One of our important highlights in 2002 was the feature article "Nonlinear Photonic Crystals: Toward All-Optical Technologies" by Serge Mingaleev and Yuri Kivshar published in Optics & Photonic News in July.

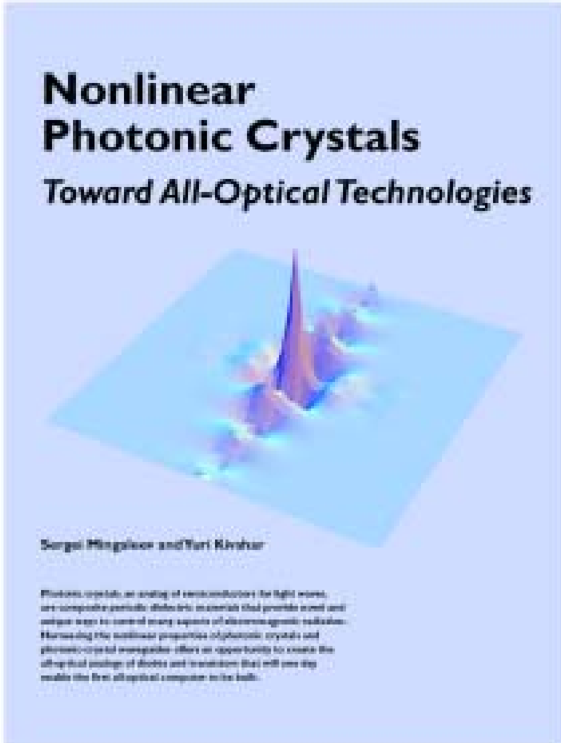
Left-Handed Materials

The study of waveguides made of the so-called left-handed materials (LHMs) is a novel direction explored by the Group in 2002. Normally light waves carry energy in the same direction as they propagate, following what is called a right-hand rule. But in 1968 Victor Veselago of the Lebedev Physics Institute in Moscow concluded that if you could tune the properties of a material just right, light would transmit energy one way while undulating in the other. In left-handed materials both the permittivity (basically the response of the material to an external electric field) and the permeability (response to a magnetic field) have negative values. This results in a negative index of refraction — when light falls on a LHM sample it refracts in a direction opposite to that for conventional materials— this "left handed" property makes a LHM a great candidate for a solid state filter or antenna.

The study of the properties of LHM is a current research project of our new PhD student Ilya Shadrivov, who joined the Group in April 2002. In particular, in collaboration with Andrey Sukhorukov, Ilya performed a systematic analysis of linear guided waves propagating in a slab waveguide made of a negative-refraction-index material, i.e. the LHM waveguide. It was revealed that the guided waves in LHM waveguides differ dramatically from conventional waves, and they possess a number of peculiar properties, such as the absence of the fundamental modes, the mode double degeneracy, and the sign-varying energy flux. In particular, the existence of novel types of guided waves with a dipole-vortex structure of the Pointing vector has been predicted.



Clusters of optical solitons predicted and analysed by the group members in 2002



Cover Stories of two issues of Optics and Photonics News in 2002 featuring the research highlights of the Nonlinear Physics Group

Applied Photonics Group

Research Accomplishments

During 2002 the Group has continued with fundamental research in guided wave photonics that relates to the analysis, modelling and design of novel light-processing devices for telecommunications and other applications. These activities have involved collaborative research with theory and experimental groups within the School, within the Australian Photonics CRC in Sydney and Melbourne, and also overseas. The outcomes of these activities include a growing number of patents. Notwithstanding the severe downturn in the photonics industry that has occurred worldwide during the past two years, there is still a significant number of research activities funded through government and commercial links.

The Group continues to play a major role in photonics education and outreach through the presentation of undergraduate photonics courses in the Faculty of Science, the inaugural Korea-Australia Photonics School in Seoul, and the annual Siemens Science Experience for high school students. There are also strong active links with the Photonics Institute in Canberra and with the Canberra Institute of Technology. Advice is also provided to the ACT government in research and education through its Knowledge Based Economy Board.

Hydrogen-Free Planar Waveguides & Devices

In collaboration with the Space Plasma and Plasma Processing Group in PRL, a new range of doped silica-based materials is being developed in thin-film form using the HARE PECVD reactor. These materials are in principle hydrogen-free, which should avoid the high optical transmission loss at 1400 nm that is prevalent in existing materials due to OH-ion absorption. Rib waveguides have been fabricated and their propagation characteristics measured, including comparison with numerical simulations of their modal fields.

Segmented Gratings

Contemporary grating-assisted wavelength add/drop filters for single-mode transmission systems either reflect light back along the fundamental mode or into the second or third mode. But even in the latter case, it is difficult to completely suppress reflection into the fundamental mode. A new class of gratings — the segmented grating — possesses specific symmetries in the waveguide cross-section that totally suppresses back reflection into the fundamental mode. The design has been patented.

Transition Loss in Bent Waveguides

When a fibre or waveguide enters a bend, there is a transition region from no loss on the straight waveguide to a continuum loss on the bent waveguide where a series of discrete radiating beams is observed. The physical mechanisms in the transition region responsible for these beams have never been fully understood, but recent numerical simulations combined with experimental work with single-mode fibres has now provided a more complete understanding.

Solitons

A number of developments included a new mathematical method for the easy analysis of cellular automata with interactions covering several neighbours and allowing for many levels. Our work on multi-soliton complexes considers solitons with many components in materials with a slow response. A chapter on this topic was completed for an American Mathematical Society book. Also, exact soliton solutions of the quintic complex Swift-Hohenberg equation, which is an important equation in determining pattern formation in dissipative systems, have been derived.

Optical Sciences Centre

Research Summary

Traditionally, nonlinear optics, solitons and light-guiding-light phenomena form the mainstream of research at the Optical Sciences Centre. Fundamental research is always our priority, so we are mostly developing ideas and concepts. One of the central ideas, namely the notion of the soliton, created a revolution in twentieth century mathematical physics. It is a notion from the theory of dynamical systems with an infinite number of degrees of freedom. We have generalised this notion from being a mode of a fully integrable system to being a mode of a Hamiltonian system, and have gone even further away to consider dissipative systems. We have also introduced the concept of multi-soliton complexes. This generalises the idea of a single soliton to more complicated objects. As an essential part of these generalisations, our research topics include, but are not limited to, a thorough theoretical analysis of optical telecommunication links, laser sources of ultra-short optical pulses, analysis of ultra-fast all-optical switches, planar integrated optic devices, Bose-Einstein condensates and basic principles of classical and quantum optics in general. The research concentrates on the most difficult and deep mathematical aspects of the above physical problems. At the same time, it satisfies the needs of most of the important applications. Nothing is more useful than a good theory. The most important theoretical predictions made in Optical Sciences Center have always been confirmed experimentally. Examples include Fermi-Pasta-Ulam recurrence, photon echo optical memory devices, ultra-short pulse propagation in birefringent optical fibers and various others. Research in such a diverse range of phenomena is done at the forefront of world trends. It is conducted in close collaboration with the leading research groups in Australia as well as around the world. Some of our research projects are done in collaboration with the Laser Physics Center (ANU). Our recent research grants were successfully achieved in collaboration with groups at the University of Sydney and the University of New South Wales. These relate to a multilevel soliton optical time division multiplexing (OTDM) dense wavelength division multiplexing ultra-high bandwidth transmission system and multi-component pulse generation and propagation in optical fibres. We also have grants from the US Army Research Office related to four-wave mixing in dispersion-managed optical fiber links and the modelling of active optical systems with nonlinear amplifiers. The goal of this research is to reach the ultimate limits of high-bit-rate all-optical information transmission. We have collaborative research projects with the University of Colorado, University of Central Florida, Instituto de Optica (Madrid), Los Alamos National Laboratories (USA), Johns Hopkins University (Baltimore), Kyushu University (Japan), City University (Hong Kong) and many other research organisations around the world. The research results have been reported at the most important international conferences and research workshops and published in the leading scientific journals.

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Matthew Hoyles, BSc (ARC Fellowship)

Visiting Fellows
Fred Barker, MSc Melb, PhD Birm (Emeritus Professor)
Shin-Ho Chung, PhD Harv
Bruce Barrett, PhD Stanford
Archie Brown, MA Glas, PhD Camb (Emeritus Professor)
Conrad Burden, BSc Qld, PhD
Tuck Choy, BSc PhD Lond
Andrew Coppel, BA Melb (Emeritus Professor)
Henry Gardner, BSc Melb, PhD (jointly with Dept. of Computer Science, FEIT)
Bertrand Giraud, BEng École Polytechnique, PhD Paris II (jointly with NP) (March – April)

Kenneth Golden, BSc Northwestern, MSc Massachusetts, PhD Paris, FAIP
Frederick Green, BSc PhD NSW
Michael Hall, MSc PhD
Roger Hosking, BSc Adel, BSc. Hon. Adel, PhD Western Ontario
Andrei Ipatov, BSc St Petersburg, PhD St Petersburg
Kailash Kumar, BSc Agra, MSc Alld, PhD McM, FAIP
Sergei Kun, MS PhD Kiev
Mihajlo Mudrinic, BSc MSc PhD Belgrade
Mohammad Nadeem, MSc Quaid-e-Asam, PhD UMIST UK
Doan Nhat Quang, Dipl TheoPhys Hanoi, PhD HUB Germany
Brian Robson, MSc PhD DSc Melb, FAIP
Robert Robson, BSc Qld, DipMet, PhD, FRMS, FAPS, FAIP (jointly with AMPL)
Michael Simpson, BSc Adel, PhD Newcastle
Susan Scott, BSc Monash, PhD Adel
Irina Talanina, MSc PhD GPI Moscow
Lindsay Tassie, MSc PhD Melb, FAIP
Helge Tverberg, Cand. real. Bergen, PhD UiB, Norway
Guy White, BSc Syd, PhD Oxford, DSc Wollongong
William Woolcock, BSc Qld, PhD Camb, FAIP
Zhang Yu-Shun, Academia Sinica, Beijing, PR China

Departmental Administrators
Mrs Heli Jackson (part time, until November)
Mrs Nyssa Gyorgy-Faul (part-time, until May)
Ms Renee Vercoe (from May)
Ms Wendy Quinn (part-time from May)

Nonlinear Physics Group

Professor and Head of Department
Yuri Kivshar, PhD USSR Acad Sci

Research Fellows
Dragomir Neshev, MSc PhD Sofia (from July)

Postdoctoral Fellow
Elena Ostrovskaya, MSc Mosc, PhD
Andrey Sukhorukov, PhD (from July)

Visiting Fellows
Serge Mingaleev, MS PhD Kiev (until May)
Sergei Kun, MS PhD Kiev (from November)
Oleg Braun, PhD DrSci Kiev (until June)
Dmitry Pelinovsky, Ms Russia, PhD Monash (from December)
Jose Ramon Salgueiro, MS PhD Santiago de Compostela (from September)

Departmental Administrator
Wendy Quinn (part-time from May, full-time from December)

Applied Photonics Group

Professor and Head of Department
John Love, MA Camb, MA DPhil DSc Oxf

Fellow
Adrian Ankiewicz, BSc BE UNSW, PhD (CRC)

Postdoctoral Fellows
Douglas Bulla, (jointly with PRL) PhD Sao Paulo

Visiting Fellows
Satis Arnold, BSc MSc UNSW, Techkne Pty Ltd
Martin Elias, ADC Australia Pty Ltd
Vika Steblina, BSc Mosc, PhD, Bandwidth Foundry
Andrew Stevenson, PhD, BSc UQ, Photonics Institute

Departmental Administrator
Wendy Quinn (part-time from May, full-time from December)

Optical Sciences Centre

Professor and Head of Centre
Allan Snyder, SM MIT, MS Harv, PhD DSc Lond, FAA, FTS, FRS

Professors
Nail Akhmediev, DSc USSR Acad Sci
John Mitchell, BSc Syd, PhD UNSW

Visiting Fellows
D'Andrea Giuliano, US Army Research Office, Far East, USA (August)
Ken-ichi Maruno, BSc Osaka, MSc PhD Kyushu (from June)

Departmental Administrator
Ms Cheryl Morse (until March)
Ms Anita Kuffner (March to June)
Mrs Amanda Greaves (from June)