The Winnipeg Institute for Theoretical Physics[1] Annual Report

September 2006 – August 2007

[1]**Web site:** http://www.physics.umanitoba.ca/WITP/witp.html

Contents

1 Director's Narrative Report

The Winnipeg Institute for Theoretical Physics was created to support theoretical physics research in Manitoba. It has carried out this mandate by encouraging collaboration between members of the Institute and by financially supporting workshops, visiting colloquium speakers, and short and long term visits by research collaborators of international standing. The permanent members of this Institute are drawn from Brandon University, the University of Manitoba, and the University of Winnipeg.

The past year was the 17th year of the Institute's existence. As usual the Institute sponsored a series research colloquia by out-of-province visitors as well as Institute members. Associated with the Permanent Members were research associates, postdoctoral fellows, and graduate students.

For the 2006–2007 academic year, the list of invited speakers is found in section 4.1. The cumulative list of graduate degrees awarded appears in section 4.2, and the published research work of permanent members is found in section 4.3. Section 5.1 contains a summary of income and expenditures for the period September 1, 2005 to August 31, 2007. The plans for the coming year include a program of invited speakers, visiting research collaborations, and the promotion of postgraduate and postdoctoral research.

Essentially all of the funds available to the Institute are spent for workshop and colloquium activities and for travel expenses of visiting scientists. The Institute has no technical support staff or administrative staff. All the administrative work is done on a volunteer basis by the members of the Institute. The Institute's funding is substantially supplemented by contributions from the NSERC grants of individual members in pursuing the Institute's mandate.

During the past academic year, the Institute's Executive Committee has consisted of R. Kobes, (Director - Winnipeg), T. Osborn (past Director - Winnipeg), and B. Southern, Director (future Director - Manitoba).

2 Current List of Members (September, 2007)

2.1 Permanent Members

- B. Bhakar [1] [4], *Ph.D. (Delhi)* [Director, Jan. - June 00]
- P.G. Blunden[1], *Ph.D (Queen's)* [Director, 93–94]
- M.E. Carrington[2], *Ph.D. (SUNY, Stony Brook)*
- T. Chakraborty[1], *Ph.D. (Dilbrugarh University, India)*
- J. D. Fiege[1], *Ph.D. (McMaster)*
- T.D. Fugleberg[2], *Ph.D. (UBC)*
- J. Hopkinson[2], *Ph.D. (Rutgers)*
- R. Kobes[3], *Ph.D. (Alberta)* [Director, 97–98, 05–07]
- G. Kunstatter[3], *Ph.D. (Toronto)* [Director, 91–92]
- P.D. Loly [1] [4], *Ph.D. (London)* [Director, Fall 99, 00-01]
- T.A. Osborn[1], *Ph.D. (Stanford)* [Director, 92–93, 01-04]
- B.W. Southern[1], *Ph.D. (McMaster)* [Director, 90–91, 07– present]
- J.P. Svenne [1] [4], *Ph.D. (M.I.T.)* [Director, 95–96]
- G.C. Tabisz [1] [4], *Ph.D. (Toronto)*
- J.M. Vail [1] [4], *Ph.D. (Brandeis)* [Director, 98–99]
- D.W. Vincent[3], *Ph.D. (Toronto)* [Director, 94–95]
- J.G. Williams[2], *Ph.D. (Birmingham)* [Director, 96–97]
- M. Whitmore[1], *Ph.D. (McMaster)*

[1] University of Manitoba
[2] Brandon University
[3] University of Winnipeg
[4] Senior Scholar

2.2 Associate Members

Research Associates

- A. Borodich (Whitmore) July '04– present
- R. E. Cameron (Tabisz) 1995– present

Postdoctoral Fellows

- W. Chen (Kunstatter/Kobes) April, 2007 – August, 2007
- Antti Gynther (Carrington) September 2006 – August 2007

2.3 Graduate Students

- Kenneth Adebayo (M.Sc.) (Southern)
- Edward Kavalchuk (Ph.D.) (Carrington/Kobes)
- Neil Moore (Ph.D.) (Whitmore)
- Adam Rogers (Ph. D) (Fiege)
- Jonathan Ziprick (M. Sc.) (Kunstatter)

2.4 Undergraduate Research Students 2006-2007

- James Babb (Kobes)
- Dylan Buhr (Kobes)
- Tarik Haroon (Manitoba Science Academy) (Vail)
- Javier Hernandez-Melgar (UM Department of Physics and Astronomy and WITP) (Vail)
- Eric Himbeault, (NSERC summer undergraduate research award) (Southern)
- Darren Leonardo (Kobes)
- Jeff Meyer (Kobes)
- Todd Sierens, (NSERC summer undergraduate research award) (Southern)
- Shawn Stargardter (Kunstatter)

3 Research Interests of Permanent Members

B. Bhakar

Present activities are directed towards the understanding of completely integrable and nonintegrable field theories in low [(1+1) and (2+1)] dimensions. Therefore, investigations are being carried out to study the behaviour of spin chain models on a lattice in (1+1) dimensions with nearest neighbour interactions only. These models are closely related to nonlinear sigma models.

P.G. Blunden

Electromagnetic interactions in complex and few-nucleon systems are being studied. I am particularly interested in the description of electron scattering at large energy and momentum transfers, the so-called quasi-elastic region, in which one or more constituents are knocked out of the nucleus. In this kinematical regime one can explore different aspects of the nuclear response to learn about two-nucleon correlations, two-body electromagnetic currents, the role of nucleon substructure, and the momentum distribution of the initial struck nucleon.

Another area of interest is in a quantum field theory of mesons and hadrons (QHD). Some recent work includes: Dirac-Hartree-Fock calculations for the properties of finite nuclei; hadronic and electromagnetic reactions; a relativistic treatment of mesonic currents; the exact numerical evaluation of one-loop quantum corrections to solitons in 3+1 dimensions; a quark-meson coupling model that treats the nucleon as a collection of confined relativistic quarks embedded in the nuclear medium; and a relativistic mean-field treatment of finite nuclei using light front coordinates.

I have a collaboration with colleagues at Jefferson Lab looking at two-photon exchange corrections in elastic electron-proton scattering. This explanation is a key to resolving a discrepancy between two experimental techniques for extracting the electric and magnetic form factors of the proton at high momentum transfer, and has important implications for our understanding of the structure of the proton.

M.E. Carrington

Field theory at finite temperature, both in and out of equilibrium, is relevant in the context of relativistic heavy ion collisions and the search for the quark-gluon plasma, and in cosmological models of the early universe.

Signatures of quark-gluon plasma formation include an enhanced production rate of real photons, or dileptons, and therefore we need to able to perform reliable calculations of these rates. A key feature in models of the early universe is the electro-weak phase transition and the associated generation of baryons. We need to develop a precise picture of this phase transition to obtain theoretical predictions of the relative abundances of light elements such as helium and lithium.

The standard technique for doing perturbative calculations at finite temperature is the hard thermal loop effective theory. This expansion is an effective reordering of the perturbation theory to take into account equivalent orders of loop diagrams to a given order in coupling. Although successful in resolving many paradoxes, there still remain some fundamental problems with this expansion in certain limits beyond its range of validity. More complicated techniques must be used when calculating quantities which are sensitive to ultra-soft energy scales or behaviour near the light cone.

Another important area of interest is the study of thermal phenomena in systems that have not reached equilibrium. Non-equilibrium phenomena cannot be treated within the usual framework of finite temperature field theory. An example of such a senario is a relativistic heavy ion collision. Such a collision is believed to produce a quark-gluon plasma which probably does not reach equilibrium before freezing out into hadrons. Non-equilibrium effects could be important when predicting signatures for quark-gluon plasma formation. Recent theoretical advances include systematic techniques (like the large-N expansion) for incorporating higher point correlations into the evolution of quantum fields, the construction of effective theories for low frequency modes, and the study of effective kinetic theories and transport coefficients in weakly coupled scalar theories. All of these techniques have applications in many other areas.

T. Chakraborty

Spin Transport in a Quantum Dot

It has long been recognized that a two-dimensional electron gas (2DEG) in narrow-gap semiconductors, particularly in InAs-based systems with its high values of the g-factor, exhibit zero-field splitting due to the spin-orbit (SO) coupling. This coupling is also the driving mechanism for making futuristic devices based on controlled spin transport, such as a spin transistor, where the electron spins would precess (due to the SO coupling) while being transported through the 2DEG channel. Tuning of this precession in the proposed spin transistor would provide an additional control that is not available in conventional devices, but may be crucial for the rapidly emerging field of semiconductor spintronics. We have developed a theoretical approach where the SO interaction is treated via exact diagonalization of the Hamiltonian for interacting electrons confined in a parabolic QD. Coulomb interaction causes energy levels to cross and at the crossing point magnetization shows a jump. In an magnetic field the strength of the SO coupling is proportional to the field (in addition to the coupling parameter and the angular momentum). Hence, the effect of the coupling is more prominent for slopes of the higher angular momenta energy curves. As a consequence, an increase in the SO coupling strength causes the energy level crossings to move to weaker fields and the jump in magnetization shows a large shift to weaker magnetic fields. This result can be exploited to tune the SO coupling strength that might be useful for spin transport.

Electron Dynamics in a DNA Molecule

The unique properties of DNA, self-assembly and molecular recognition, has rendered the 'molecule of life' a promising candidate in the rapidly emerging field of molecular nano-electronics. A recent report of a field-effect transistor based on DNA molecules, that was preceded by a series of seminal experiments on the electron conduction in DNA, has sparked a lot of interest on the electronic properties of the DNA. A thorough understanding of the electronic properties of DNA is crucial in the development of the future DNA-based nanoscale devices. In addition, charge transfer through DNA also plays an important role in radiation damage and repair and therefore important for biological processes. We have preformed theoretical calculations of the electron energy spectrum, based on a two-leg charge ladder model for the poly(dA)-poly(dT) DNA and poly(dG)-poly(dC) DNA molecules. We take the electron-electron interactions and the electron spin degree of freedom fully into account in our model. The energy spectra for the G-C and the A-T base pairs show a large gap and the interaction was found to enhance the gap. The effect of interaction is less pronounced for the G-C base pairs than that of the A-T pairs. The spin-flip excitations are not the lowest energy excitations. We also analyze the charge distribution for the ground state as well as for the excitations.

J.D. Fiege

My research program applies an advanced genetic algorithm called Ferret to several large and very difficult data-modeling problems in astrophysics. The components of this research address diverse topics that include gravitational lens physics, magnetic fields in star-forming regions, and the interstellar medium of other galaxies.

Gravitational lensing is a prediction of general relativity, in which light rays from a distant galaxy or quasar are bent by the gravity of a massive foreground galaxy or galaxy cluster. This natural lens magnifies the background object significantly but often breaks it into multiple images and distorted arcs. A new computational technique based on Ferret can determine the optimal mass distribution of the gravitational lens that is best able to re-assemble these shattered images. By applying this technique to a large catalogue of data, we will learn about the spatial distribution of dark matter in lens systems, while also obtaining images of the background sources from these natural telescopes.

Rotating disks of neutral hydrogen in nearby galaxies also allow us to probe the structure of dark matter in galaxies, since the velocity of the gas is determined mainly by the gravitational field of the dark matter. I am leading the development of a new code called "GalAPAGOS" (_Gal_axy _P_arameter _A_quisition by _G_enetic _O_ptimization _S_oftware), which use Ferret to build mathematical models of these systems, thereby determining the distribution of dark matter and properties of the gas component of gaxaxy disks.

Stars form in dense cores and filaments within molecular clouds, which are composed primarily of hydrogen gas. These clouds emit partially polarized submillimetre radiation from dust grains that are aligned perpendicular to the magnetic field, on average. I have developed software to model these systems, and plan to use the code to fit theoretical models of magnetized cores and filaments to data from the "Gould's Belt Survey" at the James Clerk Maxwell telescope, which is the largest submillimetre survey of molecular clouds to date. In addition to providing new and well explored models of molecular cloud structure, this work will help to constrain the role of magnetohydrodynamic turbulence in these systems.

T.D. Fugleberg

My current research interests are in three main areas.

The first is the study of a novel form of superconductivity called colour superconductivity. This is the study of a new state of matter - the colour superconducting state - which may be present in neutron and/or quark stars with consequences detectable in astronomical observations. The colour superconducting state arises in the theory of the strong nuclear force, Quantum Chromodynamics, (QCD). I have looked at refining models used in this analysis to include the physical masses of the quarks and other degrees of freedom in as complete a way as possible in order to make definitive quantitative predictions for observation. This research involves free colour charge and is thus related to the main unsolved problem of QCD - colour confinement.

The second area is non-equilibrium and thermal field theory. Both of these topics have important applications in the physics of the early universe and in heavy ion collisions. I am developing techniques for simplifying calculations in the real time formalism of thermal field theory. Non-equilibrium field theory is still in its infancy but has important implications in the search for the quark gluon plasma and the evolution of the universe immediately following the big bang.

The third area of research is in the area of quantum computation. A computer designed to utilize quantum mechanical indeterminacy in the computation process will theoretically be capable of solving difficult problems much more rapidly than a classical computer. This has important implications since international monetary security depends on cryptographic systems based on the fact that certain problems are "too hard" to solve in a reasonable amount of time. Since very simple quantum computers have already been constructed, quantum computation is a very important field of research. In particular I have been studying a particular model of quantum computation - adiabatic quantum computation - with the goal of gaining insight into the fundamental physical quantity or quantities responsible for the power of a quantum computer.

J. Hopkinson

An important goal of research into strongly correlated electron systems is the discovery of the physical mechanisms responsible for novel emergent phenomena. It is the collective behaviour of electrons and their spins arising from such strong correlations that leads to the realization of exotic new materials. My work is currently focused on a class of strongly correlated materials possessing local moments whose interactions are strongly frustrated by the corner-sharing triangle or tetrahedral lattice sites at which they lie. Such systems are said to be geometrically frustrated because the interactions (antiferromagnetic or ferromagnetic with a locally preferred spin direction) between pairs of spins compete in such a way as to lead to macroscopically degenerate ground states. Important questions to be addressed include: whether or not it is possible to realize a quantum spin liquid, a state with strongly correlated magnetic moments that does not order to zero temperature; whether the interplay of spin and charge frustration in magnetic metals can lead to metallic behaviour of exotic nature; and whether we can design our own artificial mesoscopic spin-ice systems. Such questions are studied by a variety of numerical and analytic theoretical techniques.

R. Kobes

The research involved falls into three related fields of interest.

The first is systems in which quantum effects are important. Quantum theory has proven difficult to interpret, with properties such as "being in two places at once" being quite unintuitive. There has been experimental work recently though on systems, usually at low temperatures, for which quantum effects are pronounced. We will study examples of such systems, such as Bose-Einstein condensation, using finite temperature field theory in order to understand better the origin of their quantum properties. Attention will be paid to systems near a critical point, in which a sharp cross-over from one type of behavior to another occurs.

The second area involves quantum computers and quantum information. During the development of quantum theory it was realized that a computer built on the principles of quantum mechanics could have a significant speed advantage over a classical computer, with recent experimental prototypes suggesting this is indeed the case. We shall examine models of algorithms used in quantum computation with a view towards understanding better which quantum effects are most responsible for the observed speed-up in the computations.

The final topic is systems in which non-linear effects are important. There are two properties of interest here: chaos (long-term unpredictability) and fractalness (self-similarity at different length scales). Such effects arise in many contexts, such as fluid flow, diffusion, chemical reactions, and biological processes. We shall examine a class of models of epidemic growth in a population, with attention paid to incorporating local interactions by analyzing such models on discrete networks. Due to the general nature, many of the tools of quantum theory, especially of systems near a critical point, will be of use.

G. Kunstatter

The quest for a theory that unifies gravity with quantum mechanics is one of the most important in theoretical physics today. Despite substantial progress in string theory and loop quantum gravity, much remains to be understood and the thermodynamic properties of black holes seem to provide valuable clues. One of the most striking properties of black hole thermodynamics is its apparent universality: it has the same qualitative features for all black holes, irrespective of which theory of gravity or which underlying microscopic theory one considers. It is this universal nature that motivates my study of the classical and quantum mechanics of generic black holes using a class of theories known collectively as two dimensional dilaton gravity. These theories live in one spatial dimension, and are sufficiently simple to be tractable but also sufficiently complex to provide insight into the microscopic origins of black hole thermodynamics. One of the projects I am undertaking is a study of the quantum dynamics of black hole formation in this general context.

A related research area is quantum computation and information theory. Quantum computers can in principle solve problems that require an exponentially large amount of resources using traditional computers. In addition, they give rise to fundamental questions about the nature of quantum information that may have application to other fields of physics, most notably quantum gravity and black hole physics. My collaborators and I have recently shown that isolated quantum systems can suffer decoherence due to quantum anomalies. This is a form of instability that arises due to the internal structure of the system under consideration. Quantum anomalies often suggest the presence of hidden degrees of freedom and can render certain systems unsuitable as components for quantum computers. More importantly, we are exploring the exciting possibility that decoherence due to quantum anomalies may help to reveal the nature of the microscopic internal degrees of freedom that account for the thermodynamic properties of black holes.

P.D. Loly

The exact count of Franklin's squares on a chessboard with students Dan Schindel and Matt Rempel occupied most of my time since the last report [online publication in March 2006, August for the print version]. This was followed by my poster at NKS2006 (Wolfram's **N**ew **K**ind of **S**cience, Washington, DC) which highlighted the Franklin work in the context of my continuing study of the scientific properties of magical squares. Ivars Peterson wrote a review of that work in Science News Online from an interview at the poster, and followed the next week with another based on 'magic square physics' with Adam Rogers. There was also renewed interest at NKS2006 and afterwards in extensions of my work on ordering the hexagrams of the I Ching, and on aspects of the compounding low order magical squares to generate larger ones with order of the product of the component orders,

In 2004 Matt Rempel had developed a remarkable proof of the preservation of the multimagic property (remaining magic after all their elements are raised to a power of 2 or 3 or more, as suggested by Wayne Chan in 2003) of certain magic squares after compounding. Also in 2004 Adam Rogers was able to completely explain the eigenproperties of compounded magic squares on the basis of the eigenproperties of their constituents. Lately I have finally been able to complete a comprehensive study of the eigenproperties of magic squares, encompassing all 880 in fourth order, and to begin to classify the 275 million in fifth order. This study with Daniel Schindel was originally focussed on singular associative (regular) magic squares but has now broadened to an understanding of the eigenvalues of non-singular magic squares, both via characteristic equations. A collaboration with Walter Trump (Nuremburg) allowed us to incorporate all singular ultramagic squares in seventh order. Recently I have found a general formula for the eigenvalues of the pandiagonal non-magic squares published in 2005 by Loly and Steeds, and have made considerable progress in finding parameterizations of various types of magic squares with the help of Dr. John Tromp, CWI, Amsterdam, in using the Haskell computer language to formulate the constraints for input to Maple or Mathematica solvers.

For more details, please see http://home.cc.umanitoba.ca/ loly/index.html.

We gave a Keynote talk at 16th International Workshop on Matrices and Statistics, Windsor, June 1-3, "Eigenvalues in the Universe of Matrix Elements 1..n-squared", with co-author Ian Cameron, and contributions from Walter Trump (Nuremberg), Adam Rogers & Daniel Schindel.

T.A. Osborn

My research program aims to achieve a unification of classical and quantum mechanics in a common mathematical framework. The theory that emerges (quantum phase space, QPS) is an altered version of classical phase space in which the usual commutative product of functions is deformed (as Planck's constant varies away from zero) into a noncommutative (star) product. With this one structural modification it is possible to state the full content of quantum mechanics as a noncommutative phase space theory. In this setting, the Schrödinger wave function never arises, Hilbert space operators are represented by phase space (Wigner) distributions, and quantum expectation values are given by integrals over phase space. This unification via QPS provides an alternate, autonomous statement of quantum mechanics that clarifies its content and interpretation and at the same time provides a new computational platform that has many parallels to that of classical mechanics.

A series of papers have investigated the quantization of charged particle systems moving in time dependent inhomogeneous magnetic fields on both flat and curved manifolds. This joint work with Mikhail Karasev has developed a QPS representation that is both gauge and geometrically covariant and has an exact star product determined by a symplectic area phase. The resulting quantum phase space that arises has a curvature which is a function of the electromagnetic field entangled with the Riemannian curvature. The discovery of this quantization induced curvature raises a variety of questions: Is this curvature really a part of nature? Can it be measured? New projects aim at establishing the ways this curvature can be detected. A natural place to look for these curvature effects is in the action-angle quantization scheme of the Old Quantum Mechanics. A general theory showing how this curvature causes corrections to the classical action functions and modifies the energy spectrum of a system has been developed. Future work will apply this theory to specific physical systems such as the Landau level problem for electron dynamics in the presence of a non-constant magnetic field. The aim here is to see if this new curvature can be experimentally verified.

B.W. Southern

Statistical Physics

Cooperative phenomena in systems with competing interactions and disorder is a topic of active study. Disorder can arise in many ways such as the dilution of nonmagnetic materials with magnetic impurities or from the loss of perfect translational order in a solid. In particular, in magnetic systems, this competition can arise from the fact that the exchange interaction between magnetic atoms oscillates with distance. If the atoms are located at the sites of a regular lattice, a state of long ranged magnetic order often occurs. However, if there is some disorder in the positions of the atoms, conflicting messages from neighbouring atoms can destroy or weaken this order. In some cases, even if the atoms are arranged so that they lie at the sites of a regular lattice and the interactions are all of the same sign but negative, the order can be weakened to such an extent that the directions of the magnetic moments at zero temperature become completely random. Such systems are said to be frustrated because of the competing interactions and, in this latter case, we refer to the system as geometrically frustrated. Frustration can lead to novel ground states and can change the nature of the excitations in the system. In particular, it can change the nature of topological defects present in the system. These topological defects can interact and exhibit nontrivial unbinding transitions as the temperature increases.Our understanding of these effects is far from complete. A variety of theoretical techniques are employed to study these systems including renormalization group methods, low temperature series methods and numerical Monte Carlo methods.

J. P. Svenne

Our current work has two main themes. The first, and currently most active one, involves work with a multi-channel algebraic system (MCAS) to study scattering of nucleons from light nuclei, and reactions initiated by such. This is a three-continent collaboration with Drs. L. Canton, G. Pisent (Padova University, Italy) and K. Amos, S. Karataglidis and D. van der Knijff (Melbourne University, Australia). The theory uses expansions in Sturmian functions of the channel-coupling interactions, leading to an algebraic solution of the coupled integral equations of the multichannel problem. This enables us to allow for the Pauli principle in the context of a collective model description of the target nucleus, by the use of orthogonalizing pseudo-potentials. The algebraic solution provides us a method of locating all resonances, no matter how narrow, as well as all bound states of the compound system, without the use of an excessively fine energy step sizes. Satisfying the Pauli principle is an essential aspect of the theory, as it removes any spuriosity, in both bound states and resonances and thus provides a theoretical formulation of the scattering problem that has predictive power. The results of the calculations can also be used to give accurate interpretation of the nuclear structure of the target nucleus and the compound system. Our first work was on the well-studied, both theoretically and experimentally, nucleus ^{12}C, with scattering by both neutrons and protons, with inclusion of the Coulomb force. The results compare very well with experiment. We are now working on other light and medium mass nuclear systems including systems well away from the valley of stability. Some very exciting new results near the proton drip line have already been obtained.

The second theme, in collaboration with L. Canton and G. Pisent at Padua University, focuses on pion absorption on very light nuclei. We have been carrying out practical calculations on ^{3}H and ^{3}He, initially with two-cluster final states; later three-nucleon final states will also be included. This uses various mechanisms and input on πN, NN and $\pi N\Delta$ interactions. The three-nucleon system is treated exactly in a Faddeev-based theory. Final-state interactions are correctly taken into account. In addition to the dominant Δ rescattering contribution to pion production, various other mechanisms, important especially near threshold, are also included. We are able to calculate, along with differential and total cross sections, all possible spin observables, measured or, as yet, not. Comparison with data, where available, is now very good. This work is continuing, and a large paper collecting our main results to date is in preparation.

G. Tabisz

My research interests involve the theoretical and experimental study of the interaction of light with molecules with the aim of obtaining information on intra- and inter- molecular dynamical processes. Current areas of special interest are nonlinear optical rotation effects in chiral molecules and the theory of collision-broadened spectral line shapes.

J.M. Vail

My research is concerned with developing and applying methods to simulate the properties of solid materials. Reliable simulation is an important complement to experiment in studying material properties where subtle variations of chemical composition, crystal structure, electronic configuration, and disorder are crucial, or where time scales, and temperature and pressure regimes are experimentally inaccessible. In 1984, with collaborators, we made a major advance in the atomistic simulation of point defects in ionic materials by combining accurate electronic structure methods for the defect with total energy analysis of the crystal. The method includes physically consistent boundary conditions, the quantum-mechanical ion-size effect, and lattice distortion and polarization, and is embodied in an automated user-friendly program. The method has been applied to charge state and structural stability of defect complexes, optical and spin resonance properties of color centers and impurities, local modification of valence and conduction band edges by impurities, derivation of effective interatomic forces, hole trapping and electron loss by impurities in oxides, local phonon mode frequencies, and classical and quantum diffusion.

Our current principal research activity is on the point defect properties in aluminum nitride, and on graphene structured systems.

D.W. Vincent

My general research interests lie in gravitation theory and early universe cosmology. I am currently involved with calculations on multidimensional cosmology solutions of Einstein's equations, which have relevance to the cosmological constant problem, the Anthropic Principle, and the Many-Worlds approach to quantum cosmology .

M. Whitmore

My research group does theoretical studies of soft condensed matter systems, in particular inhomogeneous copolymer systems and phospholipid membranes. Both these classes of molecules have relatively high molecular weights, have chemically distinct sections, and are chain-like in structure. They can self-assemble to form complex nano-scale structures, and undergo subtle phase transitions. A related system is the end-tethered polymer layer, which consists of polymers with one end anchored to a surface, all immersed in solvent. These systems are of wide interest in materials science and biological systems.

Our primary goal is to understand them at a fundamental level, primarily using computer-intensive numerical simulations, augmented by relatively simple theories to highlight the underlying physics.In the area of polymers, our primary focus is on the self-assembly of copolymers, the structures that form, the effects of additives, and the structure of end-tethered polymers. For example, we use numerical self-consistent field (NSCF) theory to calculate the phase diagrams of copolymers and copolymer/solvent blends. Recently, we have been working with chemists at the University of Toronto to understand detailed structural properties of copolymer/homopolymer blends that are observed there. The end-tethered polymer system illustrates the advantages of the NSCF approach. At high molecular weight and tethering density, the molecules become highly stretched, and the system reaches a limit known as the "polymer brush". There exist theories that describe this limit, but it has not been known at what point it is reached. In fact, it is now becoming clear that most systems that are created in the laboratory fall outside this limit. The NSCF theory gives results that are in excellent agreement with recent systematic experiments, identify the onset of the brush limit, and provide a new physical picture of the laboratory systems. Because the NSCF theory is a mean field theory, we have also done Monte Carlo simulations of many of these systems. They can also be used to construct visual pictures and movies which can provide considerable physical insight. Very recently, we have begun to extend the NSCF theory to incorporate fluctuation effects, in an attempt to understand a long-standing disagreement between theory and experiment near a mean-field critical point in the phase diagram of block copolymers. My colleague John Whitehead and I have developed an NSCF theory of phospholipid membranes. It provides a detailed picture of these systems, including a range of their structural and thermodynamic properties and their phase behaviour. It is the first theory of its kind to predict effects of pressure which are in good agreement with experiment. In particular, it predicts that the application of hydrostatic pressure causes the layer thickness to increase, rather than decrease as one might expect. We have recently extended it to mixtures of lipids of different chain lengths, and will now turn our attention to lipids with different headgroups, immersed in a variety of solvents.

J.G. Williams

One of the developing trends in general relativity has been the interest in global, as opposed to local, properties of spacetime. My current research includes spacetimes admitting gravity kinks, i.e. light cone configurations for which the cones tip over an integral number of times. Progress to date includes a kink classification for noncompact product spacetimes in both 3+1 and 2+1 dimensions and the construction of a covariant kink counting number formula in 1+1 dimensions that is related to the Gauss-Bonnet theorem and Morse's Law of Vector Fields. More recently, I have been studying aspects of a new approach to general relativity due to Ted Newman and his group: the null surface formulation. In this approach, it is the intersection of the light cone with null infinity, the so-called light cone cut, that plays the major role. The metric is no longer a fundamental quantity, but is derivable (to within a conformal factor) from the light cone cut function. Progress to-date includes the explicit construction of a light cone cut function for a (2+1)-dimensional Friedman-Robertson-Walker spacetime and the calculation of the standard

NSF functions for this model. Future effort will be directed towards the construction of such cut functions for asymptotically flat spacetimes and the analysis of any resulting singularities.

4 Research Activities

4.1 Seminars

Date	Speaker	Title
Sept 21, 2006	Dr. Jeff Williams	The Road to Relativity
Oct 12, 2006	Dr. Todd Fugleberg	Calculations in Real Time Statistical Field Theory
Oct 19, 2006	Dr. Randy Kobes	Bose-Einstein Condensates and Thermal Field Theory
Oct 26, 2006	Dr. Gabor Kunstatter	Black Holes: The Simplest and Most Complex Objects in the Universe
March 1, 2007	P. Fraser	Nuclear Structure Inputs for Multi-Channel Algebraic Scattering
March 12, 2007	Dr. David Garfinkle	The Nature of General Gravitational Singularities
June 7, 2007	Dr. Stefan Stricker	The AdS/CFT Correspondence
July 17, 2007	Dr. Karl-Peter Marzlin	Slow Photons as Charged Quasi-Particles
Sept 28, 2007	Dr. Karl-Peter Marzlin	Geometric Phases in Quantum Optics

4.2 Graduate Degrees Supervised

1. I. Abu-Ajamieh (2003) "Lateral Compression of Homopolymers and Copolymers at the Air-Liquid Interfaces for Good Solvents", M.Sc. thesis, (Whitmore)

2. Aleksandrs Aleksejevs (2005), "Next to leading order and hard-photon bremsstrahlung effects in electroweak electron-nucleon scattering", Ph.D. thesis (Blunden)

3. S. Barkanova (2004), "The Electroweak Radiative Corrections and Parity-Violating Electron-Nucleon Scattering", PhD thesis, (Blunden).

4. J. Bland (2006), Ph.D. thesis (Kunstatter)

5. J. Geehan (2002) "Self-consistent Field Theory of Compressible Bilayers: Mixtures of Two Different Chain Length Phospholipids", B.Sc. thesis (Whitmore)

6. M. Kenward (2001) "Monte Carlo Simulations of Amphiphiles: A Systematic Study", M.Sc. thesis, (Whitmore)

7. J. Medved (2000), "Thermodynamics of Charged Black Holes in Two-Dimensional Gravity". Ph.D. thesis, University of Manitoba, 2001. (University Microfilms), (Kunstatter).

8. T. Melde (2001), "The Three Nucleon System including one Dynamical Pion: A one dimensional test case". Ph.D. thesis, University of Manitoba, May 2001. (University Microfilms), (Svenne).

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13. Mirsaeed Zelli (2007), ”A Monte Carlo Study of a Family of Heisenberg Non-Collinear Magnets”, M.Sc. thesis, (Southern).

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P.G. Blunden

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8. Two-photon exchange physics: hadronic picture, Invited talk at the ECT Workshop on Two-Photon Physics, Trento, Italy, May 23-27, 2005.

9. Two-photon exchange in electron scattering: hadronic picture, Invited talk at the 2005 Joint Jefferson Lab/Institute for Nuclear Theory Workshop on Precision ElectroWeak Interactions, Williamsburg, VA, Aug 15-17, 2005.

10. Two-photon exchange and elastic electron-proton scattering, Invited talk at Workshop on Electron-Nucleus Scattering VIII, Elba, Italy, June 2004.

11. Two-photon exchange effects in electron-proton scattering, Colloquium at Argonne National Laboratory, April 2004.

12. Two-photon exchange effects in electron-proton scattering, Colloquium at University of Manitoba, November 2003.

13. Two-photon exchange and elastic electron-proton scattering, Talk presented at Fall Meeting of APS Division of Nuclear Physics, Tuscon, AZ, October 2003.

14. P.G. Blunden and A. Aleksejevs, Radiative corrections and parity-violating electron scattering, Workshop on Fundamental Symmetries and Weak Interactions, Institute for Nuclear Theory, Seattle, WA November 26, 2002 (presented by A. Aleksejevs, Ph.D. student).

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M. E. Carrington

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18. “Evolution meets Astrophysics: Advanced Genetic Algorithms for Astrophysical Data Modeling”, Aug. 25, 2004, National Research Council, DRAO, Penticton, BC (colloquium)

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Invited Presentations

1. M. D. Whitmore, *Copolymers and Computing: A Decade of Progress,* keynote talk at the High Performance Computing Systems and Applications (HPCS '06),St. John's, NL (2006)

2. M. D. Whitmore, *High Performance Computing: The New and Growing Environment in Canada,* Canadian Association of Physicists Congress, Winnipeg, Manitoba (June, 2004).

3. M. D. Whitmore, *ACEnet: Transforming Research in Atlantic Canada,* High Performance Computing Systems and Applications (HPCS '04), Winnipeg, Manitoba, (May, 2004).

4. M. D. Whitmore, *Modelling and Simulations of Self-Assembly of Block Copolymers*, High Performance Computing Systems and Applications (HPCS '02), Moncton, NewBrunswick (2002).

Contributed Presentations

5. M. D. Whitmore and Nan Zheng, *Self-Consistent Field Theory of Two-Component Phospholipid Membranes*,C.A.P. Congress, St. Catharines (2006).

6. J. G. Spiro, J. Yang, M. A. Winnik, J. P. S. Farinha, J. D. Vavasour and M. D. Whitmore,*Characterization of Nanoscopic Template Materials*, Canadian Materials Science Conference, Vancouver (2005)

7. M. D. Whitmore and R. Baranowski, *Compression of End-Anchored Polymers*,C.A.P. Congress, Vancouver (2005).

8. A. Borodich and M. D. Whitmore, *Compositional Fluctuations in Diblock Copolymer Lamellae Studied with the Method of Averaging in the Weak Segregation Limit*, C.A.P. Congress, Vancouver(2005).

9. I. Mahmoud Abu-Amajieh and M. D. Whitmore, *An Examination of the Surface-Pressure Isotherms in End–TetheredPolymer Layers*, C.A.P. Congress, Charlottetown, PEI (2003).

10. M.D. Whitmore, *Experimental and Theoretical Behaviourof End-tethered Polymers from the Mushroom to the Brush Limits*, Frontis Symposium on Chain Molecules at Interfaces: SCF Theory and Experiments,Wageningen, the Netherlands (2002).

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7. J.G. Williams , "Godel kink spacetime," (with T.A. Harriott), Gen. Rel. Grav. 33, 1753-1766 (2001)

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5 Financial

5.1 Statement of Income and Expenditures

Income

Income Source	Amount
Carry over from 2005	$6950.00
Total Funds Available	$6950.00

Expenditures

Activity	Amount Spent
Theory Canada I support	$613.00
M. Karasev	$2000.00
L. Ferchov	$214.00
M. Paranjape	$ 387.00
P. Marzlin	$ 446.00
J. Hernandez	$ 1250.00
Printing etc.	$ 308.00
Total Expenditures (2006-2007)	$5,218.00
Commitments Theory Canada 4	$ 500.00
Current funds available	$ 1232.00

In relation to the supporting funds indicated above, it should be pointed out that the members of the Institute use their individual NSERC grants to subsidize Institute activities. Currently the members from the three universities draw upon more than $350,000 of individual NSERC Research Grants. These funds have a significant fortifying effect on the level of activities in which we are able to engage. The financial contribution of the members associated with the expenses of visiting guest theorists, supports the activities and goals of the Institute, but does not appear in the budget data shown above.

The Institute has neither endowment nor trust fund support. The Institute has no significant space requirements. The occasional long term visitor requires a desk, but these needs have been accommodated by the space available to the physics departments at the member Universities. The host departments also supply occasional secretarial support such as that required for the preparation of seminar notices and research papers.

5.2 Financial Stability and Growth

The Institute has no substantial fixed costs and for this reason it is intrinsically stable. It can operate in a productive fashion at a variety of funding levels. All of the funds that the Institute receives are transformed directly into its research enhancing activities. The funds allocated to the Institute by supportive administrative bodies such as the Faculties of Science and Graduate Studies at the University of Manitoba are fortified by the individual NSERC research grants of members. This is a strong commitment to the Institute by the Institute members. In view of its overall research productivity, in terms of published papers and supervised graduate students, its capacity for running very successful conferences and workshops, and the demonstrated ability to attract excellent short-term and long-term visiting scientists, the Institute is achieving its goals. The Institute membership includes all of the theoretical physicists in the province. Hence its growth relies solely upon the associate members that it can attract (i.e. graduate students, postdoctoral fellows and research associates). The number and quality of these associate members is dependent on the Institute being able to create a positive research atmosphere. This in turn depends strongly upon the level of funding that the Institute receives. We note that significant financial support has been received from Brandon University, the University of Manitoba, and the University of Winnipeg, which will be reflected in this and the next fiscal year.

The report guidelines suggest that some indication be given of the percentage of time that members spend on Institute research. Since the Institute's programs enhance the ongoing research interests of its members, there is no distinction between individual research and Institute research. The director has spent less than 5% of his time with the administrative aspects of the Institute.