Strategic Plan for Research in Physics and Physical Oceanography

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Background

While the research of the department covers a wide range of interests, from photonics to global climate change, there are also many areas of shared expertise, from mathematical physics to computational modelling, as well as a shared approach that combines observation and experiment with theory, analysis, and numerical simulation.

Most faculty pursue a mix of fundamental and applied research, because, at its core, physics is the study of fundamental natural principles that can be applied to real-world situations. In this spirit, we fully embrace the Faculty of Science's Strategic Plan Goal to "engage with partners within and outside of Memorial to promote and support interdisciplinary research, research networking, and research collaborations.”

Much of the research in our department is aligned with the University’s Strategic Plan Research Themes, including arctic and northern regions; culture and heritage; environment, energy and natural resources; oceans, fisheries and aquaculture; and wellbeing, health and biomedical discovery.

Looking forward over the next decade, we intend that future faculty hires will be primarily driven by our strategic research focus. Our Department has two primary research strengths: Condensed Matter Physics (with a strong focus in Materials Physics) and Physical Oceanography, and a collective, significant shared interest in Computational Physics.

Materials and Marine Science are currently featured as strengths in the Faculty of Science. We intend to build upon these two core areas, and to bridge with emerging topics of University-wide interest.

Condensed Matter, Materials Physics and Theoretical Physics

Condensed matter and materials physics relate the atomic-level structure of substances
with their physical behaviors, including optical, magnetic, electronic, biological, chemical, and mechanical properties. The broad themes of this research focus in our department are magnetic and electronic materials, biological and soft materials, and photonics. Our condensed matter faculty include experimentalists (Andrews, Beaulieu, Chen, Morrow, Poduska, Quirion, and Yethiraj and cross-appointee V. Booth from Biochemistry), and theorists (Curnoe, Evstigneev, Lagowski, Plumer, Saika-Voivod). Some retirees also remain active (Clouter, Whitehead). The Faculty of Science oversees a separate interdisciplinary Ph. D. program in Theoretical Physics that is administered by members of the Department of Mathematics and Statistics and our department. Research in that field includes astrophysics (Lewis) as well as particle physics (A. Aleksejevs, cross-appointed with the Grenfell Campus of Memorial), and gravity and cosmology (I. Booth, cross-appointed from Department of Mathematics and Statistics).

We investigate condensed matter systems with a wide variety of materials properties such systems studied include semiconductors, topological insulators, superconductors, conjugated polymers, thin-film metals, magnetic materials, and quantum spin systems. Research in biological and soft materials includes studies of lipids, membranes and proteins, ordering and dynamics in colloidal systems and emulsions, cantilever-based detection of biological material as well as the study of glassy dynamics and nucleation in liquids and the theory of nano-biology. Our photonics research is devoted to the study of ultrafast nano-photonics and has a large overlap with both materials physics research and with work on spectroscopic sensors used in the investigation of materials. A particular focus of much of this research activity is to relate understanding at the fundamental level to applications that involve a wide range of potential technologies, including micro-cantilever sensors, solid-state lighting, magnetic storage, fiber optics, organic photonics and biophotonics.

We employ a large variety of experimental techniques to study these materials, including spectroscopic measurements with Raman and Brillouin scattering, ultrasound, NMR, magnetometry, X-ray absorption, micro-cantilevers, and confocal microscopy. Two state-of-the-art laboratories have been established for photonics research (ultrafast nanoscale optical and laser applications). We also use theoretical and computational methods to study the materials systems based on group theory, quantum theory of magnetism, equilibrium and non-equilibrium statistical mechanics, density functional theory, and molecular
dynamics and Monte Carlo simulations. The department maintains and continually upgrades its Centre for Magnetic and Materials Simulations (CMMS) lab, which includes office space for five graduate students and five advanced workstations. In theoretical physics our research is in the areas of the theory of general relativity, elementary particle theory, and computational astrophysics.

Our research benefits from a broad range of collaborations within our department, with other departments at MUN, and with numerous external researchers. Within the department there are extensive shared research activities in the study of magnetic properties of materials, soft colloidal and bio-systems and sensors. We also have long-standing collaborations with the members of the Departments of Biochemistry, Earth Science, Chemistry and the Faculty of Engineering. A portion of the research activity of each of our faculty members in condensed matter and theoretical physics involves work with external collaborators at universities and government laboratories around the world. Some of the research projects with industrial partners include those involving magnetic recording, solid-state lighting, biological sensors and biopharma.

Physical Oceanography

Physical oceanography is the study of physical interactions that take place in the oceans. Approaches taken include theoretical study, field observations, laboratory experimentation and numerical simulation. Observational studies must deal with the expansive space and time scales of the oceans which necessitate creative and efficient data collection schemes to achieve meaningful outcomes. These challenges drive the individual interests of researchers within the department. It is also important to recognize that the greater discipline of oceanography is inherently interdisciplinary with strong links between the physical, biological and chemical sub-disciplines; this character is evidenced by significant interdisciplinary involvement of the department faculty. The research done by the physical oceanography group covers a wide range of areas of geophysical fluid dynamics of the atmosphere and ocean, climate and ocean dynamics in the North Atlantic. The main focus of this research is on fundamental problems of the ocean and earth system and applied studies of the regional climate and ocean environment of Canada.
The oceanography group has developed a significant capacity for advanced studies and training including ocean instrumentation and computing facilities for advanced ocean observation and modelling, knowledge, experience and collaborations between members of the team. We have a substantial pool of laboratory and field oceanographic equipment including mooring equipment, ocean gliders and acoustic sensors and the ability to independently deploy these instruments in field programs around the globe, although with a primary focus on the North Atlantic. Physical oceanographers within the department cover a wide range of interests including laboratory studies, field oceanography, numerical modelling, instrumentation development, and climate studies including earth systems studies that include ice and glacial dynamics. The research of each of the faculty in oceanography (Afanassiev, Demirov, deYoung, Munroe, Tarasov, Zedel) covers most if not all of the interests listed above.

The oceanographic research interests of the department have evolved over the years but have typically covered interdisciplinary climate and ecosystem studies, acoustical oceanography, laboratory fluids studies, coastal ocean dynamics and in recent years a growing focus on instrumentation development and application. There are many opportunities within the university for collaboration and program development both inside the Faculty of Science (with Biology, Chemistry, Earth Sciences and Ocean Sciences) and with other units such as Geography, the Faculty of Engineering, and C-CORE. While the geographic focus of most of the field research has been on the Northwest Atlantic and Arctic, there are opportunities for research that reaches well beyond the Atlantic. Researchers in oceanography have been active in many different regional, national and international programs with varying themes over the years, from fisheries to instrumentation development to climate change. This flexible approach to the thematic focus of the physical oceanographic group has served it well over the years.

**Computational Physics**

The use of numerical calculations continues to expand as an integral part of condensed matter, materials physics and physical oceanographic research. Computational investigations enable a control and precision often unavailable in the laboratory. They can provide information inaccessible by other means, can guide in the design of new
experiments, and can be crucial for the development of technological devices. Computational research has become a key approach for understanding the fundamental and applied aspects of complex materials and fluids.

Theoretical and computational physics have become increasingly intertwined in recent decades, and the research activities of many members of our department reflect this evolution. These activities involve large-scale molecular dynamics, Monte Carlo and Brownian dynamics simulations, parallel tempering and free energy methods, Density Functional Theory methods, etc. Using these techniques, a broad range of topics is investigated by our faculty members, such as superconducting and magnetic systems, crystal nucleation and glass transition, organic semiconductors and electronic properties of polymers to name but a few.

Ocean modelling still includes a strong component of model development, i.e. improving process representation within the models, but is also moving towards development of tools and approaches for applied and operational oceanography. There is a very strong link between data collection and analysis and model development and verification. Strong collaboration with experimental groups, within and outside the department, is recognized as a key component of these computational research activities.

The involvement of our faculty in the remarkable expansion of computational resources available for scientific research together with the development of programs and courses in scientific computation over the last two decades is a sign of our recognition of the increasingly important role of computational physics. We were instrumental in the creation of the only interdisciplinary M.Sc. degree in Computational Science (now called Scientific Computing) in Atlantic Canada, as well as the Atlantic regional computing consortium (ACEnet), now a part of Compute Canada. Both major research groups in the department, Condensed Matter and Physical Oceanography, support and operate computational clusters for their numerical research.

**Future Plans**

We will maintain the present thematic focus of the department including condensed matter and materials physics, physical oceanography, and computational and theoretical physics. In the coming years, we will work to establish links with other thematically related groups
and researchers located elsewhere inside and outside the university. We have identified three particular opportunities for growth that build upon our existing strengths and apply to many within the department.

*Sensor and instrumentation development:* There is a strong interest in sensor development in both condensed matter physics and physical oceanography with projects and collaborators both inside the university (e.g. in Chemistry, Engineering, Geography and Archaeology) and outside the university (from the offshore industry to the lighting industry). As examples, Zedel has been working on the development of acoustics Doppler systems for sampling in nearshore waters, deYoung has been working on autonomous underwater vehicles (AUVs) and profiling mooring systems, Poduska has been working on new lighting systems and Beaulieu is developing micro-cantilever sensors for industrial and medical applications.

*Enhanced collaboration and Multidisciplinary Research* - The department will enhance and facilitate collaboration both intra-departmental and extra-departmental. We will work to encourage seminars by potential collaborators from outside the department. Initiatives such as Magnetic North and Ocean Gliders Canada were led by researchers in the department and are good examples of multi-institutional and interdisciplinary initiatives that we will encourage and support. We will foster research into new areas that build on our discoveries and achievements in materials physics (such as archaeological research) and in oceanography (such as ecosystem studies). Links to other departments and faculties of the university, from Arts to Engineering, can be further developed around the shared strategic interests of our department that align with other groups. These exist in several different thematic areas, from the development of computational techniques to integrating physical oceanographic models with biological observations.

*Biophysics and medical physics* – There are several faculty in the department (Morrow, Poduska, Saika-Voivod, Yethiraj) and several outside the department (from Chemistry and Biochemistry for example) with an interest in enhancing the level of activity in biophysics through initiatives such as a multi-disciplinary journal club and networking symposia with external visitors. There is also an opportunity to collaborate with medical physics research
interests in the Faculty of Medicine. Such collaborations could provide a possible basis for the development an undergraduate or graduate program in biophysics or medical physics.