Theoretical Physics Institute (TPI) Symposium 2003

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The Theoretical Physics Institute (TPI) at the University of Alberta consists of members from three different departments (Physics, Mathematical and Statistical Sciences, and Chemistry). The idea of this Symposium was to bring together members of the Institute, their students and post-doctoral fellows, as well as colleagues from other universities in the West, for two days designed to promote exchange of ideas and collaboration. In keeping with this intent the workshop centred around two main activities:

• Plenary review talks by speakers from institutes in Western Canada and the Western United States

• Short presentations by participants; this included presentations from faculty members, visitors, RA's/PDF's, and graduate students. These talks covered topics ranging from theoretical biop[hysics to advanced loop calculations in particle physics.

Professor Werner Israel gave a very lucid talk about the status of research regarding the question of the cosmological constant. The issue is that the expansion of the universe appears to be accelerating and observations give a small effective cosmological constant. Some of the old puzzles concerning vacuum fluctuations and their role in the evolution of the universe were discussed. Various theoretical approaches and proposed mathematical models to answer these questions were reviewed.

Another topic reviewed was the subject of Lattice Gauge Calculations in particle physics. A review of the historical development of this technique was given. The method of Monte Carlo simulations was described as most appropriate for these calculations. Results obtained for heavy flavour physics (i.e. systems made up of massive quarks) were discussed. Similarities and differences with lattice simulations in condensed matter physics were noted; in particular the problems posed by the 'chiral extrapolation' and the 'quenched fermion' approximation were noted.

The appearance of order in many body systems such as atoms and nuclei was the subject of a talk entitled "Order from randomness in many body systems". Rotational and vibrational excited states in nuclei are examples of such orderly behavior. The talk discussed novel techniques that allow physicists to carry out elaborate calculations of the structure of atomic nuclei without resort to the calculational short cuts and truncations used in the past. Calculations such as "the no-centre shell model calculations" are now able to describe many of the regularities in light atomic nuclei.

In plasma physics and condensed matter, some overviews were given; a couple of talks focussed on exact cluster methods, including Quantum Monte Carlo and a path integral approach. An entire session was devoted to superconductivity, mainly concerning the high temperature cuprate materials. However, no unifying principles emerged. It remains the case that the many body problem is a very difficult one, and the emphasis is on improved algorithms for existing theoretical methods. It may also be the case that complicated materials simply cannot be described by rather simple models.

Finally, in mathematics it is clear that quantum field theories in physics remain an inspiration for novel mathematical insights.

Terry Gannon explained what monstrous moonshine is: a mysterious relation in pure math between number theory (e.g. modular functions) and algebra (e.g. the Monster finite group). The present explanation of this uses perturbative string theory, or what is essentially the same thing, conformal field theory (i.e. conformally invariant quantum field theory in 1+1 dimensional space-time). The idea is that the algebra describes the symmetry of the conformal field theory, and the number theory concerns its partition function and 1-point 1-loop functions. Borcherds noticed that the conformal field theory can be replaced by something which is mathematically simpler: a purely algebraic structure called a vertex operator algebra. For example, the familiar notion of a "quantum field" changes from being an operator-valued distribution on space-time, to being a formal power series in a complex variable z whose coefficients are operators on state-space.

This resulting algebraic structure is still quite complicated though, and many people have argued that we still don't have our finger on the fundamental underlying principle which connects number theory with algebra. Gannon concluded his talk by speculating on what that underlying principle could be. We should ask ourselves what is so remarkable about quantum field theories in 2-dimensions. The answer, he suggested, is the possibility of braid group statistics (i.e. anyons). Thus, a natural guess for the underlying principle of moonshine is that it involves the braid group. His talk was concluded by briefly explaining how the braid group can be used to explain a baby example of moonshine: the modularity of lattice theta functions.

A workshop of this nature necessarily covers a wide variety of topics. Nonetheless, it seems that many areas in the sciences share common ground insofar as the techniques to describe them share the same mathematical basis. Many of these potential connections remain to be exploited.