Hybrid Mesons, QCD, Relativistic Boundstates and Strings

Hybrid mesons, quark antiquark boundstates in which the gluonic degrees of freedom are in an excited state, are currently a subject of intense theoretical and experimental interest. I recently showed in collaboration with M.G. Olsson and S. Veseli that the excitation states of the gluonic degrees of freedom seen in lattice simulations of QCD with fixed quark and antiquark sources are well described by string-like excitations of the QCD field. This should also hold true when the quarks at the end of the string are not fixed. I have developed a relativistic description of these string-like excitations starting from the Nambu-Goto action. We are working to predict the spectrum of the resulting hybrid mesons numerically. We are also investigating quark mass corrections to the energies when the quark masses are small.

We recently published a QCD-inspired model that reproduces all the good features of scalar potential models, such as linearly rising Regge trajectories, but which is more realistic as it contains a Lorentz vector potential. In the limit of small quark mass, the wave equation reduces to that of the scalar potential. I have derived the Salpeter kernel for this model and we are working to find its spectrum numerically.

I am very interested in the dynamics associated with the formation of chromoelectric "flux tubes" in QCD and am working to connect the monopole currents and their fields that are seen in lattice simulations with simple geometric constructions in first-quantized string theory.

BRST Quantization and Constrained Mechanical Systems

The quantum description of constrained theories such as Yang-Mills, general relativity, and string theory, has been a continuing interest of mine. My thesis work was on the use of constrained quantization in point particle mechanics and string theory, especially the problem of quantizing the manifestly supersymmetric string and particle theories. With my graduate student Dennis Crossley, I extended the BRST quantization method to systems with complex classical constraint functions and non-hermitian quantum constraints. We published two papers, one describing a formalism in which it is possible to quantize systems with complex first-class constraints, for which the BRST charge is not hermitian and another paper in which we solve the same problem when the complex conjugates of the constraints are linearly dependent upon the constraints themselves. We are investigating the application of these methods to the quantization of gravity in Ashtekar's new canonical variables.

Gravity in Self-dual Variables

Much of the work I have been doing on BRST quantization in the last few years has been in the direction of applying these methods to quantum general relativity in Ashtekar's new canonical variables. BRST methods can be used to factor out the infinite gauge volume in an inner product and generally yields a larger class of physical states than Dirac quantization. It is also our hope to obtain a larger class of physical states than the knot invariants that are the only physical states known at present, and to try to connect the BRST formulation with the spin network description that has recently been developed. For his Ph.D. thesis, my student Dennis Crossley applied the methods we worked out together to Ashtekar gravity. We found that we can construct a hermitian BRST charge for this theory that is nearly polynomial.

The Fractional Quantum Hall Effect

I have continuing interest in the physics associated with the fractional quantum Hall effect and, more generally, the physics of charged particles in magnetic fields. With former UW-Madison graduate student Andrew Bordner, I developed an effective field theory description of the fractional quantum Hall state. We determined the most general non-relativistic theory that admits charged vortex states and we performed a collective coordinate quantization of the vortices. Together with Dennis Crossley, we compared the reduced phase space and Dirac-Gupta-Bleuler quantizations of charged vortex mechanics and found that the equivalence of these two methods of quantization depends upon the quantum statistics of the vortices. These two methods produce Hamiltonians with different spectra when the vortices have anyonic statistics.