Isaac Newton Institute for Mathematical Sciences

Strong Fields, Integrability and Strings

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The two central theories in modern theoretical physics are those of gauge fields and of strings. Quantum gauge fields start from allying the principles of quantum mechanics governing the behaviour of matter at microscopic scales with Einstein's special theory of relativity, and in particular its implication that points separated in space are causally independent, incapable of influencing each other except by exchanging signals constrained to travel no faster than light.
If the field's behaviour is to be invariant under some symmetry operation, then it should be possible to choose the symmetry transformation independently at different locations. This local 'gauge' symmetry principle is enormously powerful, and the resulting theory, utilising various of the simpler possible symmetries, forms the basis of the Standard Model of particle physics, in which elementary particles such as electrons or quarks interact through exchange of mass less 'gauge Bosons' such as gluons, or the (more familiar) photon. Gauge fields are also rich mathematically – indeed, a rigorous derivation of their spectrum, and in particular of the mass of the lightest possible particle in a pure gauge theory, is one of the Clay Institute's seven millennium prize problems in mathematics.

However, the unification of the quantum theory of fields with that of gravity, Einstein's general relativity theory, remains incomplete. The central candidate (which has been a rich vein of exploration for over thirty years) is string theory, in which gauge fields naturally occur at the ends of open strings, and gravity appears naturally in loops of closed string.

It has always been clear that there is a close and rather mysterious relationship between string and gauge theories. Indeed, string theory as first proposed had nothing to do with gravity but was intended as an explanation of the strong nuclear force, later described by a gauge theory, QCD, which now forms part of the Standard Model. String theory naturally requires spacetimes with more dimensions than our three space and one of time, and we now understand that the full picture is considerably richer and more complicated, consisting of particles, strings, and higher-dimensional objects such as membranes moving in a still higher-dimensional background. In this picture we live in a three-dimensional membrane, and the particles of the Standard Model (of which we are made) are the ends of strings moving in higher dimensions. A good analogy is this: imagine you are in a darkened room, and you see many points of light apparently moving on a sphere. No simple model occurs to you which can explain their dancing motion, until you switch on a background light and see that they are the ends of the fibres of a fibre-optic 'UFO' lamp.

A common feature of recent progress in the gauge/string correspondence has been integrability. In parallel to gauge and string theories, there are many simpler but mathematically elegant models in various branches of physics – field theories, models of interacting fixed numbers of particles on a line, chains and lattices of coupled spinning objects, models with solitary moving waves called 'solitons' – which have this special mathematical property enabling their solution. Their mathematical structures, such as their hidden symmetries and the systems of equations determining their spectra, are appearing ubiquitously in calculations which link gauge and string theories, especially in the much-studied case of the 'AdS/CFT correspondence'.

The programme covers a broad sweep of ideas, from the theory required to explain both current and imminent experiments probing the Standard Model, computational approaches to its solution via high performance computers, to mathematical explorations of the gauge/string correspondence and integrability. While the programme will progress through this sweep over its duration, its goal is to bring together theorists who are interested in a wide range of these ideas and enable interchange of ideas across the full range of the programme.