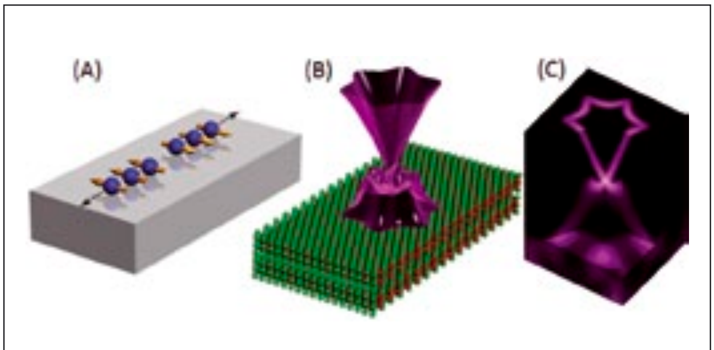
Topological Insulators



Yulin Chen, Rahul Roy and John Chalker

One of the successes of physics in the 1930s was the use of quantum mechanics to understand the difference between metals and insulators in terms of electron energy bands. Remarkably, we have discovered over the past few years that a key feature was missing from the picture we've accepted for nearly eight decades. This is that insulators come in two types, now known as 'ordinary' and 'topological'. Oxford Physics is closely involved with these developments: one of the leading theorists in the field, Rahul Roy, spent two years in the Oxford Condensed Matter Theory group as a postdoctoral research fellow before moving to a faculty position at UCLA; and Yulin Chen, an expert in the experimental techniques used to probe these new materials, has recently joined the Department from Stanford.



Surface conduction of topological insulators: (A) The spin of electrons on the surface is correlated with their direction of motion. (B) The lattice structure of Bi_2Te_3 and the predicted relativistic "Dirac cone" like electronic structure formed by the surface electrons. (C) The electronic structure measured by angle-resolved photoemission that confirmed the theoretical prediction and the topological nature of Bi_2Te_3.

Rahul Roy writes: Imagine taking a block of wood and coating its surfaces with silver. Then the block would be a bulk insulator with a metallic conducting surface. A 'topological insulator' is similar to a coated block, but whereas cutting the wood block would create new insulating surfaces, cutting a topological insulator creates new conducting surfaces. My work uses the mathematics of topological invariants to predict that certain insulating materials will have surface modes for electrons, which are robust because they are protected by symmetry from, for example, the effects of impurity scattering. Experiments with a number of materials, ranging from HgTe/HgCd heterostructures to Bi_2Te_3 have vindicated these predictions, and many examples of topological insulators are now known.

Yulin Chen writes: Oxford is setting up a programme to study the physics of these novel materials and find how we can tailor them to potential applications. The taskforce will include several local institutions: Oxford Physics, where a laboratory is being constructed for advanced angle-resolved photoemission spectroscopy (ARPES) so we can directly measure electronic structures; the Diamond synchrotron light source; and the central laser facility of the UK Scientific and Technology Facilities Council. This coalition will bring our research to the forefront of this exciting new field.

PREDICTING... Predictability

Hannah Arnold

You want to go to the beach at the weekend: which of the following do you think is the more useful weather forecast: a) next weekend will be dry; or b) next weekend the probability of rain is just 10%? Both are possible ways of presenting the same forecast, though only the second acknowledges that our prediction about next weekend's weather involves uncertainty.

There are two main sources of uncertainty in our weather forecast, both of which must be accurately represented. The first is initial condition uncertainty. The atmosphere is a chaotic system, so errors in the starting conditions for our forecast (i.e. errors in the measurements we make of the weather today) can lead to large deviations in the predicted weather for the weekend. The second is model uncertainty. In order to make the forecast, we have had to represent the atmosphere, oceans and land, and their many interactions, in a piece of computer code, which introduces other errors. In particular, we have to represent unresolved small scale processes, such as clouds, in some way, which involves major simplifications and approximations. My D.Phil. work involves developing a new technique (involving stochastic mathematics) for representing the small scales in an atmospheric model, providing a physically motivated way of representing model uncertainty. We have found the forecasts made using this technique are very reliable; if you look at all the occasions when we have forecast a 10% chance of rain, on average it rains 10% of the time. This is very important for climate change prediction, where we are interested in how the statistics of the weather will change due to anthropogenic forcing. We must be confident that our model accurately represents today's climate in order to trust the climate it predicts for the future.

In the atmosphere, it has been found that certain weather patterns are very predictable – the errors due to initial condition and model uncertainty stay small as we look to the future. However, on other occasions, including these representations of uncertainty leads to a large divergence in the forecast for the weekend, indicating the atmosphere is in a very unpredictable state. It is only by accurately representing uncertainty that we can estimate how predictable the atmosphere is now, and tell you whether taking an umbrella to the beach next weekend might be a good idea or not!