Liu and colleagues have now carried out a comprehensive study of Bi_2Se_3 films grown by molecular beam epitaxy. They find that most parts of the film are indeed strain-free, but also that strain does exist around grain boundaries — defects inherent to the growth of this material by molecular beam epitaxy. Growth initiates with grains nucleating randomly on the substrate. As the grains grow, they eventually coalesce and form grain boundaries. Much like paving a floor with randomly placed ceramic tiles, they do not quite come together perfectly at the boundaries. The orientation of the grains is often different, which yields grain boundaries with different angles[1].

By quantitatively analysing the structure of the grain boundaries, strain fields and surface states, the team was able to show that Dirac-point shifts are proportionally correlated with the magnitude of tensile strain (Fig. 1a). However, a bandgap of about 60 meV is found for regions under compressive strain — the Dirac cone structure vanishes (Fig. 1b). The results are reproduced by density-functional calculations.

The work of Liu and colleagues, involving ingenious experiments to access various strains within a crystal, establishes the effect strain can have on the electronic properties of topological insulators like Bi_2Se_3. However, it should be noted that the strain investigated by the authors arises from proximity to grain boundaries. In principle, strain can also be applied externally, in a controlled way, to the topological insulator's surface. The development of a suitable strain gate (for example, piezoelectric) may provide a viable way to dynamically tune the surface states in a topological insulator for practical applications[10]. In particular, using strain as a switch between normal insulator and topological insulator states could prove to be a good platform for exploring and manipulating Majorana fermions. ❒

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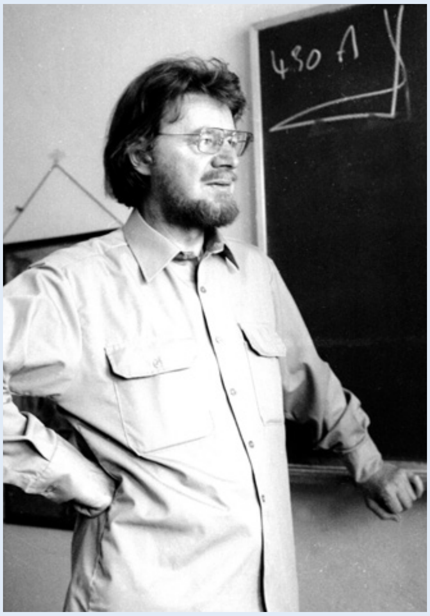
Published online: 16 March 2014

BELL'S THEOREM

Closing the loopholes

Fifty years ago, in a paper that has become one of the most important results of quantum theory, John Stewart Bell (pictured) revisited the Einstein–Podolsky–Rosen paradox. Using elegant mathematics he showed that no hidden-variable theory, intended to restore causality and locality, could be compatible with the predictions of quantum mechanics.

Bell imagined a pair of spin-half entangled particles at remote locations and assumed that the spins could be measured along independently chosen axes. The correlation between the outcomes of the two measurements, as predicted by quantum mechanics, turns out to be different from the correlation given by local hidden-variable models. Hence, this is a test of the validity of any local hidden-variable theory: for the theory to hold, the correlations need to satisfy certain constraints — known as Bell's inequalities. Conversely, any violation of these constraints provides proof for nonlocality.



Despite the fact that all experimental evidence so far seems to confirm the predictions of quantum mechanics, local hidden-variable theories cannot yet be completely discarded because no experiment has been able to simultaneously eliminate all possible loopholes. There are several ways in which an experimental test of the Bell theorem can go terribly wrong. First, the experimenter must make sure that there is no possibility of communication between the two measurement locations: this 'locality loophole' can be closed if the duration of the measurements is shorter than the time required for a light-speed signal to travel between the two sites. Another loophole is 'fair-sampling' — an apparent violation of Bell's inequalities caused by imperfect detection efficiency — although this has been recently closed (M. Giustina *et al. Nature* **497,** 227–230; 2013).

A third issue is the detector-setting independence, or 'freedom of choice' loophole. Bell's theorem assumes that measurements are made along independently chosen directions, but if the detector settings have been predetermined by some prior communication, then this could lead to a violation of Bell's inequalities without nonlocal correlations. To close this loophole, Jason Gallicchio, Andrew Friedman and David Kaiser propose an experiment that would make such a conspiracy impossible (*Phys. Rev. Lett.* **12,** 110405; 2014). So far, quantum random-number generators have been used to set the direction of the detectors: Gallicchio *et al.* propose instead to use light from cosmic sources. Certain astrophysical objects have non-overlapping light cones, meaning that any pre-arranged outcome would have to have been set a very long time ago — for instance, for quasars at opposite sides of the sky, that timescale would be billions of years; another possibility would be to use light from patches of the cosmic background radiation.

Back in 1964, could Bell have imagined that, half a century later, such bold ideas might take his theorem from the blackboard to the skies?

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