Current flowing along the edges of a promising quantum device is insensitive to its magnetic impurities

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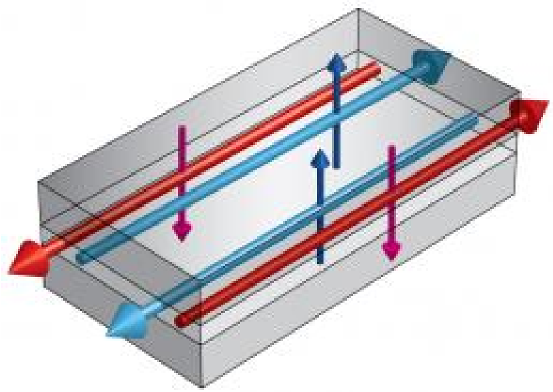

Figure 1: Electrons at the edge of the material mercury-telluride exhibit the quantum spin Hall effect, in which two oppositely spin-polarized charge currents (indicated in red and blue) circulate along the edge without generating heat.

Conductors of electrical current, including copper, heat up and limit the ability to increase circuit densities. Unusual materials that exhibit the so-called 'quantum spin Hall effect', in which current can flow without dissipating heat, could provide an alternative to conventional metals. However, internal imperfections, such as magnetic impurities, were assumed to disrupt current flow. Now, using theoretical calculations, a research team from Japan and the US has shown that devices built from these alternative materials are surprisingly immune to the presence of magnetic impurities.

Soon after it was predicted in 2005, experimentalists discovered the quantum spin Hall effect in thin layers of the semiconductor mercury-telluride. The signature of the effect is two counter electric currents—with oppositely 'spin-polarized' charges—that circulate along the edge of the film (Fig. 1). Each current has the same universal quantum of conductance as a quantum wire. Because the currents are resistant to scattering, these 'edge states' flow without dissipating heat.

As the edge states appear only within a few degrees above absolute zero, however, devices made from these materials require further development to be of practical use. Magnetic fields are also known to disrupt the edge states, so physicists assumed that a magnetic impurity, such as a lone iron atom near the edge of the film, would do the same.

"We wanted to better understand how the conductance of the edge states might be affected by magnetic impurities," says Akira Furusaki, a scientist at the RIKEN Advanced Science Institute, Wako, who co-authored the work. Other groups have calculated how edge states scatter when encountering an impurity, and concluded that it would considerably lower the conductance of a spin-Hall device.

Furusaki and his colleagues redid this calculation using the same theoretical model as the other groups, but included the frequency dependence of the current. They used a so-called 'rate equation approach', where the current is obtained by solving a master equation that describes the time evolution of the magnetic impurity that scatters the edge states.

Since the researchers found that magnetic impurities do not actually change the conductance of edge states, at least for direct currents (DC), they concluded that quantum spin Hall devices could be more robust to magnetic impurities than previously thought.

Furusaki plans to further extend the theoretical model to “study the stability of edge states in the presence of strong electron interactions, where the fractionalized quantum spin Hall effect is predicted.”

More information: Tanaka, Y., et al. Conductance of a helical edge liquid coupled to a magnetic impurity. Physical Review Letters 106, 236402 (2011).

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