Hall Effects

The Hall effect can come in classical or quantum forms. The quantum version is an emergent property of vast numbers of electrons, which underlies the phenomena seen in many topological materials, such as topological insulators.

Classical Hall Effect:

(a) A current flows along the length of a slab made from an electrically conducting material.

(b) If a magnetic field is applied, the electrons in the current will be bent to one side of the material. To compensate, a net positive charge accumulates on the opposite side. This leads to a transverse voltage difference — the Hall voltage — appearing across the slab.

Quantum Hall Effect:

(d) Electrons within the slab are deflected so strongly that, in effect, they are confined to moving in closed in loops. No current flows within the bulk of the slab. But electrons can hop along the edge of the material, conducting electricity, almost without resistance.

(e) The circling motion restricts the energies that electrons can have to discrete values. In turn, the quantum Hall resistance rises in discrete steps as the magnetic field increases. This is the integer quantum Hall effect. For very strong magnetic fields, electrons form collective structures with a fraction of the charge of an electron. This is the fractional quantum Hall effect.

Quantum Spin Hall Effect:

(f) In some materials, each electron’s spin can become coupled to its motion — even in the absence of an external magnetic field, due to internal magnetic effects. Electrons that are spin ‘up’ will flow around the edge in one sense, while those that are spin ‘down’ will travel in the opposite sense. Such effects are extremely robust, making them ideal candidates for new types of electronic devices that are fast, energy efficient and resilient against data corruption.