2.5: Anisotropic electrical conductivity

The current density, $\boldsymbol{J}$, is related to the electric field, $\boldsymbol{E}$, by

$$\boldsymbol{J} = \sigma \boldsymbol{E}$$

In an analogous way to thermal conductivity, the current density does not have to be parallel to the electric field. Three different examples of anisotropic electrical conductivity are described here. These show how the anisotropy is related to the crystal structure.

In metals, conductivity occurs by transport of delocalised electrons through the crystalline lattice, under the influence of an applied electric field. The conductivity is limited by the scattering of the electrons by imperfections in the periodicity of the structure (vibrations, impurities, etc). Because of the high symmetry in cubic metals, the overall drift velocity is parallel to the electric field, i.e. there is an isotropic response. However in hexagonally "close packed" metals, the nature of the symmetry in the crystalline array allows the conductivity to be anisotropic. For example in cadmium, it varies from $1.3 \times 10^7 \text{Sm}^{-1}$ along the six-fold axis to $1.5 \times 10^7 \text{Sm}^{-1}$ perpendicular to that axis.

Graphite consists of layered planes of carbon atoms with a structure as shown below. The layers are stacked above one another in a staggered fashion, the spacing between layers being about 2.3 times the distance between the adjacent carbon atoms in a layer.
The Hexagonal Structure of Graphite Planes

Here the hexagonal carbon rings provide the delocalised electrons, allowing easy conduction within the planes. Conduction is very much less perpendicular to the planes (around three orders of magnitude smaller) - this is highly anisotropic behaviour. The structure also creates anisotropy in other properties of graphite, such as thermal conductivity and thermal expansion.

This planar anisotropy is also seen in high temperature superconductors like BiSrCaCuO. The copper oxide "ab" planes provide superconducting pathways for electrons, but such pathways are not available perpendicular to the planes.