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# Resistance and electrical conductivity of metals

Quantum mechanics states that electrons in an atom cannot take on any arbitrary energy value. Rather, there are fixed energy levels which the electrons can occupy, and values in between these levels are impossible. When a large number of such allowed energy levels are spaced close together (in energy-space) i.e. have similar (minutely differing) energies then we can talk about these energy levels together as an "energy band." There can be many such energy bands in a material, depending on the atomic number (number of electrons) and their distribution (besides external factors like environment modifying the energy bands).

The material's electrons seek to minimize the total energy in the material by going to low energy states, however the Pauli exclusion principle means that they cannot all go to the lowest state. The electrons instead "fill up" the band structure starting from the bottom. The characteristic energy level up to which the electrons have filled is called the Fermi level. The position of the Fermi level with respect to the band structure is very important for electrical conduction: only electrons in energy levels near the Fermi level are free to move around since the electrons can easily jump among the partially occupied states in that region. In contrast, the low energy states are rigidly filled with a fixed number of electrons at all times, and the high energy states are empty of electrons at all times.

In metals there are many energy levels near the Fermi level, meaning that there are many electrons available to move. This is what causes the high electronic conductivity in metals.

An important part of band theory is that there may be forbidden bands in energy: energy intervals which do not contain any energy levels. In insulators and semiconductors, the number of electrons happens to be just the right amount to fill a certain integer number of low energy bands, exactly to the boundary. In this case, the

Fermi level falls within a band gap. Since there are no available states near the Fermi level, and the electrons are not freely movable, the electronic conductivity is very low.

A metal consists of a lattice of atoms, each with an outer shell of electrons which freely dissociate from their parent atoms and travel through the lattice. This is also known as a positive ionic lattice. This 'sea' of dissociable electrons allows the metal to conduct electric current. When an electrical potential difference (a voltage) is applied across the metal, the resulting electric field causes electrons to move from one end of the conductor to the other.

Near room temperatures, metals have resistance. The primary cause of this resistance is the thermal motion of ions. This acts to scatter electrons (due to destructive interference of free electron waves on non-correlating potentials of ions). Also contributing to resistance in metals with impurities are the resulting imperfections in the lattice. In pure metals this source is negligible.

The larger the cross-sectional area of the conductor, the more electrons per unit length are available to carry the current. As a result, the resistance is lower in larger cross-section conductors. The number of scattering events encountered by an electron passing through a material is proportional to the length of the conductor. The longer the conductor the higher the resistance. Different materials also affect the resistance.

When analyzing the response of materials to alternating electric fields, in applications such as electrical impedance tomography, it is necessary to replace resistivity with a complex quantity called impeditivity (in analogy to electrical impedance). Impeditivity is the sum of a real component, the resistivity, and an imaginary component, the reactivity (in analogy to reactance). The magnitude of Impeditivity is the square root of sum of squares of magnitudes of resistivity and reactivity.

Conversely, in such cases the conductivity must be expressed as a complex number (or even as a matrix of complex numbers, in the case of anisotropic materials) called the admittivity. Admittivity is the sum of a real component called the conductivity and an imaginary component called the susceptivity.

An alternative description of the response to alternating currents uses a real (but frequency-dependent) conductivity, along with a real permittivity. The larger the conductivity is, the more quickly the alternating-current signal is absorbed by the material (i.e., the more opaque the material is).

Literature:


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