Factors Influencing Thermal Conductivity in Applied Physics

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Commentary

Received: 07-Nov-2022 Manuscript No. JPAP-22-82442; **Editor assigned:** 10-Nov-2022, Pre QC No. JPAP-22-82442(PQ); **Reviewed:** 24-Nov-2022, QC No. JPAP-22-82442; **Revised:** 01-Dec-2022, Manuscript No. JPAP-22-82442(A); **Published:** 08-Dec-2022, DOI:10.4172/2320-2459.10.7.004.

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ABOUT THE STUDY

A material's thermal conductivity is a measure of its ability to conduct heat. Heat transfer occurs at a slower rate in low thermal conductivity materials than in high thermal conductivity materials. Metals, for example, have high thermal conductivity and are very efficient at conducting heat, whereas insulating materials like Rockwool or Styrofoam are the opposite. Materials with high thermal conductivity are commonly used in heat sink applications, while materials with low thermal conductivity are used as thermal insulation. Thermal resistivity is the reciprocal of thermal conductivity.

Influencing factors

Temperature: Temperature has a different effect on thermal conductivity in metals and nonmetals. Heat conductivity in metals is primarily due to free electrons. Thermal conductivity of metals is approximately proportional to absolute temperature (in kelvins) times electrical conductivity, according to the Wiedemann-Franz law. The electrical conductivity of pure metals decreases with increasing temperature, so the product of the two, the thermal conductivity, remains approximately constant. However, as temperatures approach absolute zero, thermal conductivity falls precipitously, because the change in electrical conductivity is usually smaller in alloys, thermal conductivity rises with temperature, often proportionally. The peak thermal conductivity of many pure metals ranges between 2 K and 10 K. Heat conductivity in nonmetals, on the other hand, is primarily due to lattice vibrations (phonons). With the exception of high-quality crystals at low temperatures, the phonon mean free path is not significantly reduced at higher temperatures. As a result, the thermal conductivity of nonmetals is nearly constant at high temperatures. Thermal conductivity and heat capacity decrease at low temperatures well below the Debye temperature due to carrier scattering from defects.

Chemical phase: When a material changes phases from solid to liquid is known as chemical phase. When ice melts to form liquid water at 0°C, for example, the thermal conductivity changes from 2.18 W/(mK) to 0.56 W/(mK). Even more dramatically, a fluid's thermal conductivity diverges near the vapor-liquid critical point.

Thermal anisotropy: Non-cubic crystals, for example, can have different thermal conductivities along different crystal axes. With 35 W/(mK) along the c axis and 32 W/(mK) along the an axis, sapphire is a notable example of variable thermal conductivity based on orientation and temperature. Wood conducts better along the grain than across the grain. Metals that have been heavily cold pressed, laminated materials, cables, materials used in the Space Shuttle thermal protection system, and fiber-reinforced composite structures are other examples of materials whose thermal conductivity varies with direction. The direction of heat flow may differ from the direction of the thermal gradient when anisotropy exists.

Electrical conductivity: According to the Wiedemann-Franz law, thermal conductivity in metals is approximately correlated with electrical conductivity, as freely moving valence electrons transfer not only electric current but also heat energy. However, due to the increased importance of phonon carriers for heat in nonmetals, the general correlation between electrical and thermal conductance does not hold for other materials. Silver is less thermally conductive than diamond, which is an electrical insulator but conducts heat *via* phonons due to its orderly atomic array.

Magnetic field: The thermal Hall Effect, also known as the Righi-Leduc effect, describes the effect of magnetic fields on thermal conductivity.

Gaseous phases: Air and other gases are good insulators in the absence of convection. As a result, many insulating materials simply function by having a large number of gas-filled pockets that block heat conduction pathways. These include expanded and extruded polystyrene, silica aerogel, and warm clothing. Fur and feathers, for example, are natural biological insulators that trap air in pores, pockets, or voids.

Low density gases with high thermal conductivity include hydrogen and helium. Dense gases with low thermal conductivity include xenon and dichlorodifluoromethane. Because of its high heat capacity, sulfur hexafluoride, a dense gas, has a relatively high thermal conductivity. Argon and krypton, gases denser than air, are frequently used to improve the insulation properties of insulated glazing (double paned windows).