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Constitutive Theory of Heat Transfer

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Extended Abstract

By the second law of thermodynamics, there exists a physical quantity Q that, at a given instant, is associated with each surface in a non-isothermal body. This quantity can be interpreted as the heat flux through the surface and has two fundamental properties: behaving additively on compatible material surfaces and satisfying the first law of thermodynamics. These two properties, when rendered precise, imply the existence of the flux vector field $\boldsymbol{q}$ whose scalar product with the unit normal to the surface yields the surface density of the heat flux Q. The main aim of heat transfer studies is to predict and control $\boldsymbol{q}$.

For the heat transfer in a rigid body without macroscopic relative motion (pure heat conduction), $\boldsymbol{q}$ is proportionally related to the temperature gradient by the classical Fourier law of heat conduction, an empirical fundamental law in heat conduction. Such a relation is, however, not available for the heat transfer in a body with macroscopic relative motion such as moving fluids and solids in deformation (convective heat transfer). We developed this relation for both heat conduction and convective heat transfer by finding both the necessary and sufficient condition in a systematic, rigorous way for a heat transfer process to satisfy the principle of frame-indifference and the second law of thermodynamics. This leads to a generalized Fourier law that relates $\boldsymbol{q}$ to the temperature gradient and generalizes the classical Fourier law to the convective heat transfer. Such a study is of fundamental importance because heat transfer research aims to predict and control the rate at which the heat is transferred.