Characteristic dimensions for heat transfer

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Resumen

Teniendo en cuenta la necesidad y la importancia de introducir en el currículo de estudio de física e ingeniería los conceptos fundamentales relacionados con la transferencia de calor, en este trabajo, a partir de las soluciones de la ecuación de conducción de calor no estacionaria, discutiremos las escalas espaciales y temporales involucradas en las leyes de ese fenómeno y los límites de validez de su descripción actual, con la esperanza de que esos conceptos puedan ser de utilidad para profesores y estudiantes.

Abstract

Taking into account the actual need and importance of introducing the main concepts of heat transfer in the curriculum of science and engineering studies, and starting from the solutions of the non-stationary heat conduction equation, we discuss the length and time scales involved in the laws of this phenomenon and the limits of validity of its current description, hoping that these concepts can be helpful for teachers and students.

Keywords: Transferencia de calor, dimensiones, fonones

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I. INTRODUCTION

The conduction of heat in solids is a well known phenomenon, whose mathematical description dates from about two hundred years before, when Fourier [1] stated the famous law having his name. However, the role played in these phenomena by the thermal parameters governing the heat transport is often not well known or it is misinterpreted [2]. In particular, there are some characteristic (length and time) dimensions playing a very important role in the understanding of heat transfer phenomena. As there are many size and time dependent physical properties (in other words, these properties can be different for dissimilar phenomena), it is of great importance to deal with this theme with students (and teachers) at a college and university level. Therefore, it is the main objective of this work to define, in a phenomenological and easy accessible way, characteristic lengths and time dimensions for the very important phenomena of macroscopic heat transfer and to discuss about the limits of the laws describing it. This paper is distributed as follows. In the next section the laws of macroscopic heat transfer by conduction will be presented and the physical meaning of the involved thermal parameters will be briefly discussed. Sections III and IV will be devoted to the analysis of characteristic length and time scales respectively, both within the frame of non-stationary heat conduction in the presence of pulsed heat sources. In section V an analysis of the limiting scales for periodical heat sources will be presented. The above aspects will be summarized in section VI together with the conclusions.

II. LAWS OF MACROSCOPIC HEAT TRANSFER BY CONDUCTION

It is well known that any temperature difference within a physical system causes a transfer of heat from the region of higher temperature to the one of lower. This transport process takes place until the system has become uniform temperature throughout. The rate of heat flux (units of W) transferred per unit time, t, depends on the nature of the transport mechanism, which can be radiation, convection or conduction (or a coupling of then) [3]. In this paper we will focus our attention to heat transfer by conduction in condensed matter, for which the local heat flow-rate in some direction, r, of homogeneous material is governed by Fourier's law:

$$\Phi = -kA\nabla T \,. \tag{1}$$

The thermal conductivity, k (W/mK), is expressed as the quantity of heat transmitted per unit time, t, per unit area, A, and per unit temperature gradient $\nabla T=\partial T/\partial \mathbf{r}$. The negative sign indicate that heat flow will take place in the opposite direction of the temperature gradient. It characterizes stationary processes of heat transfer.