Thermal Physics Concepts: The Role of the Thermal Effusivity

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Inspired by a previously published *TPT* article,[1] this paper describes the concept of thermal effusivity and the role of this parameter in understanding thermal physics concepts, in particular the fact that when we touch objects of equal temperature but of different materials we often feel that one body is "hotter" or "colder."

In the above mentioned article, Yeo and Zadnik present an instrument to assess in students a wide range of beliefs or understandings about thermodynamic concepts. Their "Thermal Concept Evaluation" consists basically of a questionnaire with 26 multiple-choice items about heat energy and temperature, allowing students to apply either everyday physics or classroom physics in their responses. In question 16 (see Fig. 2 in Ref. 1) students are asked about the preferred explanation of the following situation:

> *Kim takes a metal ruler and a wooden ruler from a pencil case. He announces that the metal one feels colder than the wooden one.*

The authors of the paper suggest that of the five possible responses, the best explanation of the described effect is that *metal conducts energy away from his hand more rapidly than wood.* This assertion, in our opinion, can lead to the mistaken notion that the relevant thermophysical parameter for the described phenomenon is the very well-known thermal conductivity k instead of the thermal effusivity ε, whose role is usually undervalued and/or misunderstood, but which can be exploited in advanced introductory physics courses, especially at the high school level, where the analysis of energy transport problems presented in standard textbooks does not make any use of its concept. Therefore, it is the objective of this paper to discuss briefly the meaning of this parameter and its role in transient heating phenomena. For this purpose we will make use of the example described above.

Thermal effusivity, also called "contact coefficient" by some authors,[2] is defined as

$$\varepsilon = \sqrt{k\rho c} = {k}/{\sqrt{\alpha}} = \rho c\sqrt{\alpha}\,, \tag{1}$$

where α is the thermal diffusivity, ρ the mass density, and c the specific heat.[3] An extended explanation of the physical relevance of the parameters governing the generation and propagation of heat energy in solids can be found in many books, monographs, and articles.[4-7]

Thermal conductivity is defined by Fourier's law of heat energy conduction[8] and measures the energy flow per unit time through a unit area of a unit thickness of a material that has a unit temperature difference between its opposite faces. On the other hand, a time-varying phenomenon is described by the differential equation of thermal diffusion[9] (energy conservation law), also requiring knowledge of the thermal diffusivity and effusivity. The former is the quantity associated with the speed of propagation of energy in a material as its temperature changes. If the changes are periodic, the thermal effusivity comes into play, determining the magnitude of the temperature at the solid surface. In this case, the temperature field behaves as an at-