Blackbody Radiation and the Loss of Universality: Implications for Planck's Formulation and Boltzman's Constant

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Through the reevaluation of Kirchhoff's law (Robitaille P. M. L. *IEEE Trans. Plasma Sci.*, 2003, v. 31(6), 1263–1267), Planck's blackbody equation (Planck M. *Ann. der Physik*, 1901, v. 4, 553–356) loses its universal significance and becomes restricted to perfect absorbers. Consequently, the proper application of Planck's radiation law involves the study of solid opaque objects, typically made from graphite, soot, and carbon black. The extension of this equation to other materials may yield apparent temperatures, which do not have any physical meaning relative to the usual temperature scales. Real temperatures are exclusively obtained from objects which are known solids, or which are enclosed within, or in equilibrium with, a perfect absorber. For this reason, the currently accepted temperature of the microwave background must be viewed as an apparent temperature. Rectifying this situation, while respecting real temperatures, involves a reexamination of Boltzman's constant. In so doing, the latter is deprived of its universal nature and, in fact, acts as a temperature dependent variable. In its revised form, Planck's equation becomes temperature insensitive near 300 K, when applied to the microwave background.

With the formulation of his law of thermal emission [1], Planck brought to science a long sought physical order. Though individual materials varied widely in their radiative behaviors, Kirchhoff's law of thermal emission [2, 3] had enabled him to advance dramatic simplifications in an otherwise chaotic world [1]. Given thermal equilibrium and enclosure, the blackbody cavity seemed to impart upon nature a universal property, far removed from the confusion prevailing outside its walls [4]. Universality produced conceptual order and brought rapid and dramatic progress in mathematical physics.

In his "Theory of Heat Radiation" [4], Planck outlines the prize: the existence of the universal constants, h and k. Moreover, he is able to introduce natural units of length, mass, time, and temperature [4; §164]. He writes: "*In contrast with this it might be of interest to note that, with the aid of the two constants h and k which appear in the universal law of radiation, we have the means of establishing units of length, mass, time, and temperature, which are independent of special bodies or substances, which necessarily retain their significance for all time and for all environments, terrestrial and human or otherwise, and which may, therefore, be described as 'natural units'*" [4; §164]. Planck then presents the values of the four fundamental constants [4; §164]:

Planck's constant $h = 6.415{\times}10^{-27}$ g cm^2/sec,
Boltzman's constant $k = 1.34{\times}10^{-16}$ g cm^2/sec^2 degree,
the speed of light $c = 3.10{\times}10^{10}$ cm/sec,
the gravitational constant $f = 6.685{\times}10^{-8}$ cm^3/g sec^2.

Finally, he reveals basic units of:

length $\sqrt{fh/c^3} = 3.99{\times}10^{-33}$ cm,
mass $\sqrt{ch/f} = 5.37{\times}10^{-5}$ g,
time $\sqrt{fh/c^5} = 1.33{\times}10^{-43}$ s,
temperature $\frac{1}{k}\sqrt{c^5h/f} = 3.60{\times}10^{32}$ degree.

Planck continues: "*These quantities retain their natural significance as long as the law of gravitation and that of the propagation of light in a vacuum and the two principles of thermodynamics remain valid; they therefore must be found always the same, when measured by the most widely differing intelligences according to the most widely differing methods*" [4; §164].

The real triumph of Planck's equation [1] rested not solely on solving the blackbody problem, but rather on the universal nature of h and k. The four fundamental units of scale for time, length, mass, and temperature profoundly altered physics. It is in this light, that concern over any fundamental change in Kirchhoff's law [2, 3] and Planck's equation [1] must be viewed.

The notion that the microwave background [5] is being produced directly by the oceans of the Earth [6–9], brings with it an immediate realization that universality is lost, and Kirchhoff's law is invalid [10–14]. Blackbody radiation is not a universal process [10–14], as Planck so adamantly advocated [4]. Yet, if the microwave background truly arises from oceanic emissions [5–8], then it is not simple to reconcile a temperature at ~3 K with a source known to have a physical temperature of ~300 K [10]. Let us examine more closely the problem at hand, by considering Planck's formulation (1):

$$\frac{\varepsilon_v}{\alpha_v} = \frac{2hv^3}{c^2}\,\frac{1}{e^{hv/kT}-1}\,. \tag{1}$$

In order to properly fit the microwave background using this equation, the problem rests in the $k\,T$ term. It is possible, for instance, to make that assumption that an apparent temperature exists [10] and to keep the meaning of Boltzman's constant. In fact, this was the course of action initially proposed [10]. In this way, nothing was lost from the universal nature of h and k [10]. But, upon further consideration, it is clear that such an approach removes all physical meaning from temperature itself. The one alternative is to alter Boltzman's constant directly, and accept the full consequences of the loss of universality. The issue involves a fundamental understanding of how energy is distributed within matter. For the microwave background, this must focus on water [8].

Thus, let us consider a very primitive description of how energy enters, or becomes distributed, within water [8]. Water possesses many degrees of freedom and must be viewed as a complex system. At low temperatures, some of the first degrees of freedom to be fully occupied will be associated with the weak intermolecular hydrogen bond ($H_2O \cdots HOH$) [8]. These involve both stretching and bending processes, resulting in several vibrational-rotational modes. The hydrogen bond ($H_2O \cdots HOH$) has been advanced as responsible for the microwave background [8], particularly as a result of its predicted bond strength. As energy continues to enter the water system, it will start to populate other degrees of freedom, including those associated with the direct translation and rotation of individual molecules. This is in sharp contrast to graphite, for instance, because the latter never undergoes a solid-liquid phase transition [15]. Eventually, other degrees of freedom, associated with the vibrational and bending modes of the intramolecular hydroxyl bonds (H–OH) themselves, will become increasingly populated. Hydrogen bonds ($H_2O \cdots HOH$) have bond strengths which are on the order of 100 times lower than hydroxyl bonds (H–OH) [8]. Considering these complexities, it is unreasonable to believe that energy will enter the water system in a manner which ignores the existence of these degrees of freedom, particularly those associated with the liquid state.

Contrary to what Kirchhoff and Planck require for universality [1–3], these complex issues extend throughout nature. Each material is unique relative to the degrees of freedom it has available as a function of temperature [15]. Water possesses two distinct oscillators, the intermolecular hydrogen bond ($H_2O \cdots HOH$) and the intramolecular hydroxyl bond (H–OH) [7]. These two oscillatory systems have very distinct energies [8] and provide a situation which is quite removed from graphite. Kirchhoff and Planck had no means of anticipating such complexity. In fact, they were relatively unaware of the tremendous atomic variability found at the level of the lattice. As such, it is somewhat understandable that they might seek universal solutions.

In any case, it has been amply demonstrated that Kirchhoff's law is not valid [10–14]. There can be no universality. In addition, it is extremely likely that the microwave background is being produced by thermal photons emitted directly from the oceanic surface and then scattered in the Earth's atmosphere [6]. This implies that a ∼300 K source is able to behave, at least over a region of the electromagnetic spectrum, as a ∼3 K source. However, since the oceans are not at ∼3 K, an inconsistency has been revealed in the determination of temperatures using the laws of thermal emission. The problem stems from the weakness of the hydrogen bond and the associated ease with which water enters the liquid state. Furthermore, it is evident that energy can enter the water system and be directed into its translational degrees of freedom, thereby becoming unavailable for thermal emission. This is a significant problem, which Kirchhoff and Planck did not need to consider, and of which they were unaware, when treating graphite boxes [1–4, 10]. Graphite, unlike water, cannot support convection.

In any event, the central issue remains that a ∼3 K temperature has been obtained from a ∼300 K source. As mentioned above, it is possible to essentially ignore the consequences of this finding by simply treating the microwave background as an apparent temperature [10], devoid of physical meaning. In this way, Planck's equation and the universal constants, survive quite nicely [10]. Conversely, if one refuses to abandon the real temperature scale, then a problem arises. In order to properly fit the microwave background with Planck's equation and a real temperature at ∼300 K, then Boltzman's constant must change. In fact, it must become a temperature dependent variable, $k'(T)$. This variable must behave such that when it is multiplied by a range of temperatures near 300 K, it results in a perfectly constant value independent of temperature ($k'(T) \cdot T = P$, where P is a constant). Planck's equation thereby becomes completely insensitive to temperature fluctuations over the temperature and frequency ranges of interest, as seen in Eq. (2):

$$\frac{\varepsilon_v}{\alpha_v} = \frac{2hv^3}{c^2}\,\frac{1}{e^{hv/P}-1}\,. \qquad (2)$$

As a result, relative to the microwave background, we move from a universal constant, k, to a temperature sensitive variable, $k'(T)$, which acts to render Planck's equation temperature insensitive. The modern value of the constant, P, for the microwave background, is approximately 3.762×10^{-16} ergs. The move away from graphite, into another Planckian system, has resulted in a profound re-evaluation of the science of thermodynamics. Boltzman's constant, therefore, remains valid only for graphite, soot, or carbon black, and those materials approaching their performance at a given frequency. Outside a certain range of temperatures, or frequencies, or materials, then other constants and/or variables, which are material specific, exist. The measure of how much energy a system can hold at a given temperature, or how temperature changes as a function of energy, is directly determined by the makeup of the system itself. The flow of heat within a system depends on all of the degrees of freedom which eventually become available [15]. In this regard, phase transitions bring with them additional degrees of freedom, either translational or rotational, which are simply not available to the solid state [15]. Herein is found the central reason for the loss of universality: phase transitions exist. Nothing is universal, since phase transitions and any available degrees of freedom [15] are strictly dependent on the nature of matter. Hence, each material must be treated on its own accord. This is the primary lesson of the water/microwave background findings.

Physics cannot maintain a proper understanding of temperature without abandoning the universal attributes of Boltzman's constant. Otherwise, the temperature scale itself loses meaning. In order to specifically address the microwave background, Boltzman's constant, in fact, can become a temperature dependent variable. At the same time, since many materials contain covalent bonds with bond strengths near those found within graphite, it is likely that many material specific constants will, in fact, approach Boltzman's. Nonetheless, relative to the microwave background, a temperature dependent variable exists which acts to completely remove all temperature sensitivity from Planck's equation at earthly temperatures. This explains why Penzias and Wilson [5] first reported that the microwave background was devoid of seasonal variations.

As regards to Planck's constant, and the fundamental units of time, mass, and length, they appear to remain unaltered by the findings prompted by the microwave background. Perhaps they will be able to retain their universal meaning. However, a careful analysis of individual physical processes is in order, such that the consequences of the loss of universality can be fully understood.

Dedication

This work is dedicated to my wife, Patricia Anne, and to our sons, Jacob, Christophe, and Luc.

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