On Temperature Radiation

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Abstract

In this work we compare two blackbody interpretations, those of G. Kirchhoff and M. Planck. We separate the problem of interpreting the blackbody spectrum from that of determining the mechanical equivalent of radiation. Then we propose that, if we set aside characterization of the blackbody, electromagnetism suffices to analyze spectral distribution and leads to interpreting it as determined by the receiver band-pass.

1 Introduction

Although the blackbody cannot be considered an elementary substance in a chemical sense, G. Kirchhoff considered it simple for thermodynamic interpretation of spectral properties. Indeed, he introduced it to demonstrate a theorem of capital importance in thermodynamics: that which fixes the relationship between emission $E$ and absorption $A$ of light and heat. According to the theorem, it makes sense to speak of thermal radiation if and only if for each pair of bodies $C_1$ and $C_2$ is equal to $E_1/A_1 = E_2/A_2$. The prerogative of the blackbody $C_S$ is $A_S \equiv 1$. In the analysis of M. Planck however, the blackbody has lost the most fundamental property attributed classically to matter because it is an empty cavity at thermal equilibrium. It is clear that if the blackbody is identified with a “macroscopic” electromagnetic field, the latter appears as the most elementary of thermodynamic bodies, to wit, temperature radiation. But it is necessary to bear in mind that fields are the solutions of the Maxwell equations. As J. Clerk Maxwell explains, the equations describe the experiments of M. Faraday and give formal dress to his ideas. The physical interpretation of the solutions is less immediate. Therefore, identifying temperature radiation with an electromagnetic field neither specifies concretely the properties of
Planck’s blackbody nor interprets physically a solution of Maxwell’s equations. Rather, that identification mixes two theoretical formulations having different assumptions to explain the phenomenon of heating by irradiation.

In this work we examine briefly the question of the existence of thermal emission on the basis of the properties which thermodynamics assigns it. On the one hand, electromagnetism does not specify any property for radiation while on the other it describes a mode of propagation incompatible with the second principle of thermodynamics. Indeed, it is linked historically with the development of telecommunications. But heat is not transferred from a warmer tank to a cooler tank by this technology but only a signal (the image) from a broadcaster to the receiving station regardless of the thermal gradients.

The most notable consequence of this analysis is the impossibility of determining an energy interpretation of the thermodynamic type \[1\] for electromagnetism.

## 2 A thermometer based on the brightness of hot bodies

Around 1860 Gustav Kirchhoff wrote the famous article, “über das Verhältnis zwischen dem Emissionsvermögen und dem Absorptionsvermögen der Körper für Wärme und Licht” in which he sought to give a definition of the thermometer alternative to that proposed by Lord Kelvin \[2\]. In it he defined the “blackbody”. Although this body, thus introduced, has a very well defined function in thermodynamics – that of measuring high temperatures – it cannot have a structural connotation quite as well defined for a reason which we shall try to clarify.

It is possible to use the luminous emission of a blackbody, for example the incandescence of the surface of a platinum wire, for measuring temperature if it is possible to calibrate in thermometric degrees a scale of luminous intensity or colors with its aid. If this is possible, the temperature can be read after the measuring blackbody has led to thermal equilibrium by intimate contact with the body whose temperature it is desired to measure. But light can be detected at a distance. Therefore it might be possible to measure the temperature at a distance by comparison of the light emitted by the body and that of a blackbody taken as standard (for instance by making use of a pyrometer). Since, unfortunately, different substances display appreciable variations in absolute emissive power, it can be asked whether the claim of graduating the temperature according to optical properties might have some basis.

Now let us clarify better the notion of optical thermometer. “Thermometer” is any object suitable for reproducible temperature measurement. “Optical” means that it functions with no need of being placed in close contact with the body having unknown temperature. The other way round, any luminous object can function as an optical thermometer if it is possible to define the luminous equivalent of temperature. In other words, in principle, evaluation of tempera-
ture by the radiation emitted has sense if there is temperature radiation. This, according to Kirchhoff, implies a value of the ratio between absolute emissive power and absorptive power dependent only on temperature. There are two alternatives.

A. The first assumes that, experimentally, a sufficiently broad class of materials has well-defined thermal behavior and is linked to a radiative process. Logically, temperature is then conceived as an equivalence relation between the bodies. Since thermodynamics admits that a system can pass from the initial state to the final state only by traversing states of equilibrium, the thermodynamic parameters of the process can be attributed to the state of the system. If the radiative process passes through states characterized by temperature alone, then a function of the luminous emission measures it.

B. The second alternative conjectures that all energy exchanges, and thus those of radiating energy too, are governed by thermodynamics. That is to say that the heat radiation exchanged is included in the energy balance and that radiation spreads from the hotter bodies to the colder ones. In the latter case a light parameter must be among the variables characterizing the process and must depend on temperature. Alternative B requires that measurements depend on the initial temperature difference between the thermometer and the object. Clearly, the same requirement applies to thermometers which function by contact. Except that it is known that the latter do not satisfy it. Specific heat $\chi = dQ/dT$ was introduced just because heating of bodies originally at different temperatures and placed in contact depends on their nature as well as their respective initial temperatures. Incidentally, the heat exchanged to reach the temperature of equilibrium, measured so as to be an additive magnitude, could replace temperature in thermodynamics. The problem is that it is not at all obvious what heat is. On the contrary, until now it is known only what it isn’t; it is not a variable of state.

Let us explain this last statement better. Historically, Rumford was the first to interpret the need for continuous cooling when profiling cannon barrels in such a manner that the production of shavings produced heat. Hirn and Joule used industrial systems to appraise as accurately as possible the amount of heat produced in relation to the work carried out by systems and agreed to interpret their measurement by saying that heat is, like mechanical work, a form of energy. The effort was considerable even if, the principle being established, the values found by those measurements can be checked in the laboratory with instruments which heat up little and convert little work into little heat, that is, when considerable fluctuations occur. But if the heat produced work in accordance with a constant relationship, the temperature might be associated with the work of expansion of a gas thermometer. That heat cannot be considered a variable of state when the system exchanges work was the unfortunate fact if we like.

After this short digression let us go back to temperature measurement and introduce the thermodynamic thermometer of Lord Kelvin with which we propose to compare Kirchhoff’s. Lord Kelvin, as everybody knows, managed to
define temperature independently of the particular thermometer basing himself on a cyclic process\(^1\). Thanks to him, thermodynamic temperature is an additive magnitude. But it is also an absolute magnitude in the sense that the zero on the scale is not arbitrary. The choice, which expresses giving up defining the thermometer operationally, became necessary due to the Joule-Kelvin\(^2\) effect. Lord Kelvin, after being persuaded that in any case an ill-defined thermometer does not allow establishing a unique mechanical equivalent of heat, redefined the thermometric scale on Carnot’s ideal gas engine\(^3\). The reversibility of the cycle allows unequivocally defining the mechanical equivalent of heat. In addition, very general considerations on the impossibility of perpetuum mobile of the second kind allow keeping the same value of the equivalent, independently of the absolute temperature value. In this manner however there appears to be a thermodynamic state well defined at temperature zero. In addition, the choice of defining temperature on a rational basis\(^4\) instead of empirically, makes thermodynamics a prescriptive theory. In other words, this thermodynamics is not a discipline which describes facts subject to measurement error, but a mathematical one which deduces ideal universal processes from equations. Functional mathematical dependence defines the thermodynamic potentials of energy, enthalpy, free energy, and entropy. Mathematics itself cannot be correct “on average” but only correct or, if the equations are incoherent, incorrect. This

\(^1\)This is not a periodic process in the sense that it spontaneously takes on the initial conditions at the end of the period but one which again takes on the initial value of the internal energy (\(\Delta U = 0\)) when the other variables of state are taken back to the initial values, i.e. \(\Delta Q = \int_{p}^{v} d\) on the cycle. In other words, the process is not identified with rotation of the vanes of a steam turbine and it is not inverted by inverting the direction of rotation of the vanes.

\(^2\)Called also “Joule-Thomson effect”. It is the effect which allows obtaining dry ice from carbon dioxide at surrounding temperature without doing work (for the work of expansion of freezing water, compare. Mach, p. 234\(^3\)). As this means that the material states associated with thermodynamic processes are not unequivocally defined by the parameters, it leads to rejecting Alternative A.

\(^3\)Let us recall that in the Carnot cycle an ideal gas is, let us say, constrained to do work. The motor consists of one insulated cylinder with the exception of the base, and is equipped with one free thermally insulated piston. To work in the adiabatic/isothermal cycle it is placed alternately on an insulated stand or on one or the other of two stoves which are kept at temperatures \(T_{1}\) and \(T_{2}\) respectively. Its thermodynamic cycle takes place then between two temperatures \(T_{1}\) and \(T_{2}\) which are prevented from balancing themselves at the \(T_{\text{mean}}\) such that \(T_{1} < T_{\text{mean}} < T_{2}\). Nor is the number of rpm mentioned because the cycle must function under conditions of thermodynamic equilibrium. This essential hypothesis excludes that a pressure difference be created between external and internal pressure at the cylinder (i.e. there must not be friction between the piston and the cylinder) and that the heat flows by conduction between the thermal baths and the piston. This hypothesis failing, Carnot’s machine might not at all perform its duty despite the thermal gradient. Carnot’s machine differently from Watt’s or Otto’s, which do not satisfy the hypothesis, has the prerogative of being reversible. In this context, “reversible” means essentially that if a Carnot machine is connected to a Carnot refrigerator between the same two temperatures, it still must not be possible to transfer heat from the colder thermostat to the other. The postulate that the energy balance per cycle of the two (perfect) connected machines is null is equivalent to the postulate that the Carnot machine is ideal or reversible. It is also important to remember that the second principle, taken for the Carnot cycle, is universally valid in thermodynamics. Indeed, the energy statement is independent of the particular mechanism considered.
seems to us to be the manner in which a thermal phenomenon is measurable without thermodynamics being phenomenological.

The approach of Kirchhoff diverges from that of Lord Kelvin because the German physicist starts from the assumption that thermodynamics must be prescriptive. His blackbody is a thermometer because it satisfies the same relationship between heat and temperature that the absolute thermometer satisfies and not because it exists in our world. This means that he does not consider the demonstration of his own theorem like a description of an observation.

In the demonstration, Kirchhoff takes into consideration any body \( C \) having as its property that its radiation depends only on temperature and on wavelength since in any case \( C \) can be colored. He shows that the process or absorption/emission is cyclical and is in agreement with the principles of classical thermodynamics (alternative B). For this purpose he makes use of a characteristic property of the mirror, which, in the case of the blackbody, is summarized, "A mirror which reflects a blackbody is black". Since, the other way around, "an optically machined black glass is a mirror", it is seen that at thermodynamic equilibrium the absorption/emission process is cyclical because it has the (optical) effect of a reflection. According to us, since heat does not produce work in accordance with a fixed relationship, the (mechanical) effect of a pressure cannot be attributed without further ado to optical reflection. Indeed, a "Carnot cycle" written to justify heat conduction between two thermal baths with different temperatures does not justify concomitantly the mechanical work of a thermal machine. In the same way, the substitute for the Carnot cycle proposed by Kirchhoff to justify the use of the pyrometer does not justify the mechanical work carried out by an electric motor. The \( E/A \) relationship between emissive and absorptive power of the body \( C \) measures temperature because the internal energy changes by \( \Delta U = \chi \cdot \Delta T \) absorbed with the change in temperature of the stove, where \( \chi \) is precisely the specific heat of the body. Under the new conditions of equilibrium, \( E/A \) measures the new temperature of the body \( C \).

Instead of going into the details of the demonstration, let us consider the adherence of the terms to the facts. The first part of the thesis (stated in his num. 3), or the rule that emission be proportional to the absorption of a body for each wavelength of the radiation, is not in conflict with experience. Instead, the assertion that there is temperature radiation is not supported experimentally at least in three circumstances, which we recall below. Indeed, the theory postulates that at thermal equilibrium radiation depends only on temperature and possibly on wavelength, that it takes on a *homogeneous and isotropic distribution in space*\(^4\). But, experimentally, the emission of electromagnetic radiators, called *antennas*, does not possess the required characteristics of homogeneity and isotropy, nor does it take them on at thermodynamic equilibrium with a cylindrical, cubic or prismatic metallic container with optically machined walls. Not even the light of a common incandescent light bulb generally displays an ef-

\(^4\)This does not occur “on average” but because the independence of radiation energy from spatial variables was postulated. In thermodynamics, wavelength is not in relation with the normal vibration modes of a box.
efficient emission/absorption mechanism to establish thermodynamic equilibrium; if it remains lit and is visible from any point in a room it does not evolve towards a situation of “equilibrium” illumination characterized by the impossibility of distinguishing it from the wallpaper. In other situations involving measurement of power distribution it is not at all based on equilibrium; to affirm that radiation from the sun goes to thermal equilibrium with a thermometer located here on earth is ticklish from an experimental and a strictly theoretical viewpoint.

In conclusion, the operating principle of the optical pyrometer is justified by thermodynamics (alternative B) but the absorption/emission process is as ideal as the Carnot cycle.

3 The quantum energetics interpretation

In the preceding paragraph we saw that in thermodynamics the requisite of a thermometer, or indifferentely an object whose temperature can be measured, is to possess a temperature independent of chemical composition or structure. We also saw that Kirchhoff assumed a universal principle, which governs energy exchanges (alternative B of the preceding num.) rather than attributing energetic states to matter (alternative A). Is it possible as an alternative to identify radiation with a form of energy?

M. Planck answered affirmatively. Indeed, he borrowed the statistical mechanical interpretation of entropy expressly for interpreting by a characteristic function the form of spectral radiation of hot bodies on the most updated data of O. Lummer and E. Pringsheim. Now, in these experiments the oven is empty. Hence the void exhibits special dependence on the wavelength of the emission of the blackbody better than any hot material object. That is to say, the property of being black belongs to radiation.

The characterizations of radiation which come out of the classical optics framework develop, in our opinion, along three mutually independent lines, to wit, statistical (*), energetic (**) and electromagnetic (***)

Since Planck desired to underscore the originality of his approach as compared to that adopted by W. Wien or L. Boltzmann for extrapolating the less updated data, he has become indeed the promoter of the explicative use of mechanical modeling (*) while continuing to insist that he wishes to pursue the work of clarification of the Maxwell equations (***) undertaken by H. Hertz (***)

**From approximately 1\(\mu\) up to 18\(\mu\), for temperatures from 87 \(K\) to 1650 \(K\).

**In this context, “empty” stands for “containing a diathermanous medium”, eventually at a low pressure (in the theory of heat, diathermanous means transparent).

**He expressed himself thus, “the job of finding a modification [of the Maxwell theory] allowing for the new facts without sacrificing its best parts seems to me much more promising. In accordance with this criterion, the theory of radiation developed by myself will, in my opinion, reveal itself to be the most fruitful [of those thus far mentioned]. It is divided in two perfectly distinct parts, to wit, the electrodynamics theory of elementary oscillators and the statistical theory of these oscillators”. Ann. Phys. 31:758 (1910).
Planck’s formula of irradiation from hot bodies does not represent energy distribution neither according to Boltzmann nor according to Hertz.

3.1 States of light (*)

The division between classical ("macroscopic") system and surrounding environment (the rest of the world) is typical of the thermodynamics approach to the study of energy exchanges. One imagines the system being studied enclosed by a geometrical surface that ideally separates it from the environment. Exchanges of mechanical energy, heat, or even mass through the surface are considered measurable with instruments like the thermometer and the calorimeter. It is also thought that the system relaxes spontaneously until it settles into an indefinitely stable condition as a consequence of the failure of the constraints responsible for the initial differences in temperature, pressure and volume between system and environment. Classically, the thermodynamic potentials are attributed to the process and the accent is placed on the overall energy balance between the initial stable state and the final state of the system. But the definition of the absolute thermometric scale determines the problem of characterizing the states of matter in thermodynamics. The first theory which seeks to trace the thermal properties of the states back to dynamics, takes the name of kinetic theory. The latter does not consider the thermodynamic states as mere “calculative expedients” but associates with them dynamic properties deduced from an ad hoc model. Since dynamics is based on observations, it seems that, if a model allows justification of mathematical expressions of the state functions, thermodynamics will be refounded on physical principles.

According to Boltzmann, kinetic modeling is obtained by separating the thermodynamic system into a large number of equal elements, atoms or molecules, individually satisfying the laws of classical mechanics. Indeed, for the purposes of dynamics, any material system can be represented by marking out its elements (material points) subject to conservative forces. But each thermodynamic system is supposed to be a material system and therefore the same separation into elements ("microscopic" subsystems) must apply. The correspondence between the variables which dynamics associates with the number of material points (considered as components of a "macroscopic" system) and the thermodynamic variables is not one to one. This is clear, according to Boltzmann. Indeed, thermodynamics labels only the states of equilibrium, that is the stable ones. And it must be possible to label them in an univocal manner, i.e. by adding a sufficient number of particular "thermodynamic" parameters, because the thermodynamic problem is that of univocal characterization of states. In a word, the physical properties of the system represented by thermodynamic functions do not apply to each atom but emerge from collective behavior at thermodynamic equilibrium. Since neither the laws governing the dynamic

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8In a number of the order of that used by Avogadro during the volumetric determination of chemical reactions.

9The common indicator diagrams in the Cartesian plane connect only possible states of equilibrium. Therefore, on those diagrams there are no states different from those of equilib-
elements nor those which apply to the overall system are considered statistical in classical physics, what is statistical in the kinetic model is the collective behavior at equilibrium; it is governed by the law of large numbers.

An interpretative problem of thermodynamics emerges because the magnitudes involved in atoms, from which the system is composed according to the kinetic model, cannot be measured in principle with classical measuring instruments. In other words, an average value is not the result of a statistical regularity with which a measurement error is associated experimentally. It follows that the law of large numbers is a mathematical principle. Roughly, the principle specifies the location, “to converge in probability to a variable” 11. This means that collective behavior is a probabilistic regularity in the specific sense that it assumes application of the theory of probability. This is the mathematical model on which the kinetic theory is based.

If the laws of thermodynamics must agree with the mathematics of the kinetic theory, their new interpretation differs from the classical one. Indeed, if the mathematical relation between the two types of variables - thermodynamic and mechanical - must respect the mathematical theory of probability, linear combinations of dynamic variables enter into thermodynamic functions, all the possible elementary events must be known in advance, the sure event and the impossible event are in the field of events, et cetera 12. What determines the classical probabilistic behavior of the system? Presumably the “microscopic” elements pertaining to a given thermodynamic state are shared equally as regards initial conditions. So the elementary events would be the sets of initial conditions. Since the number of events is very great but finite, the “sharing process” is not random. Indeed, the events can always be put in biunique correspondence with a finite subset of the set of natural numbers 13. Not even the real numbers associated with the temporal evolution \( t \) at the dynamical level introduce any fortuitousness under the initial conditions. At the level of motion of one individual material point, to take the system back to the initial conditions at time 2\( t \) it suffices that the boundary conditions reverse the direction of motion.

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10. Not those governing the evolution of the density of probability of the dynamic states.
11. We are discussing equilibrium states. Otherwise, dynamic time, defined in the dynamics of conservative systems basing on oscillatory or rectiliner motion, is not automatically the parameter governing thermodynamic relaxation also.
12. As thermodynamics is a physical theory and Boltzmann’s atoms are microscopic, it is unclear which mechanical aspect determines the thermodynamic behavior of a system. But having reached this point it is possible to exemplify at least the type of relationship sought. It is a matter of connecting the roto-translation in the space of a tossed coin – movement that can be filmed in the desired detail and reproduced by projection in “as many identical examples as wanted” – with the quantitative evaluation of the possibility that a given side will appear on top.
13. To order numerable sets (for example, the elements of a set according to decreasing values) it is necessary to postulate an axiom equivalent to well-ordering.
on the trajectory at time $t$. More generally, it is possible to classify dynamic states according to symmetry properties and consider operations which reverse the states$^{14}$. But it is necessary that the classification have a meaning. According to us, it has a meaning in mechanics but not in thermodynamics. Indeed, in hydrostatics the considerations on pressure direction rest on the fact that the surfaces on which hydrostatic pressure is exerted are precisely those of the container. But the separating surface between the thermodynamic system and the environment is largely arbitrary so that pressure in classic thermodynamics is defined in terms of elasticity of the (gaseous) system. In conclusion, evolution has no direct role in thermodynamics because the time defined in mechanics is not among the thermodynamic variables. However, the randomness at the origin of the irreversibility in Boltzmann’s kinetic model does not depend on evolution but on the arbitrariness of the boundary conditions$^7$.

Furthermore, dynamic reduction presents two essentially mathematical difficulties. First, the system contains a finite number of elements so that all the average values calculated on it can be mapped as a function of a discrete variable. But thermodynamic functions are continuous and in particular cover the whole real range of values between any pair of mean values calculated for the dynamic variables. That way, the dynamical states taken by one kinetic model only account for a set of measure zero in the graph of a given thermodynamic function. Quasi all thermodynamic states have no correspondent in the kinetic model. Second, the concept of mean value pertaining to one element of the kinetic model is not well defined. When the values can be measured, we obtain a distribution of values from which mean values can be calculated according to a number of different criteria. On atoms, such measures cannot be taken in principle. The expected value must agree with the value calculated from thermodynamic laws or whatever method of obtaining averages will give rise to significant thermodynamic magnitudes? In the first case, i.e. if thermodynamics functions are expressions not only bound to the correct unit of measure but also mathematically assigned, the statistical interpretation is misleading. As regards the second case, Einstein at last established the originality of the formula of spectral energy distribution of the blackbody with respect to the hypotheses of the kinetic theory of gasses. This means that a set of simple elements, let us say an ideal gas, is not a valid model of radiation. But Einstein’s result really clarifies only that the model assumed by Boltzmann does not allow recovering the formula of Planck; it cannot show that the characteristic function which effectively interpolates the spectral form is an energy according to Boltzmann$^{15}$. Indeed, the mechanisms of emission/absorption assumed by Einstein have nothing in common with Boltzmann’s collisions$^{11}$. After all, classical statistical mechanics had never analyzed the consequences of inelastic collisions – which

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$^{14}$To “reflect” a trajectory on itself, a correctly positioned reflecting surface is needed. To reflect $n$ of them, $n$ surfaces are needed. Mathematically, said conditions can not only be assigned but, without regard for complication, can be specified with the desired accuracy. Ignorance in principle of the experimental data associated with "microscopic" subsystems does not imply any random measurement error on the data.

$^{15}$On page 124 Einstein$^8$ comments on the expression of the density of radiation.
give rise to emissions of the type of those which occur in radioactive phenomena – on the state of a conservative mechanical system; nor did it admit directive shocks[12],[13].

Lastly, if the blackbody has merely radiative consistency, the possibility of measuring thermal equilibrium experimentally with a conventional thermometer is lacking and therefore there is no longer any guarantee that the color or the intensity of the radiation measures temperature sooner or later in the conventional sense.

3.2 Extension of energetics to nonmechanical phenomena (**) 

The other way of saying that radiation is a form of energy is to formally include radiant energy in the energy balance (hypotheses B). While not taking support from dynamic modeling, the energy approach also interprets thermology with mechanics. To clarify, the cycle of a thermal machine in the usual Clapeyron diagram was explained as a balance even under the hypothesis that heat is a form of energy equivalent to mechanical energy. As underscored in the preceding num., a balance usually considers only exchanges and not absolute values. As to exchanges, the "true" Carnot cycle maximizes the transformation of heat into work. Despite this, the thermal difference on which the cycle functions does not yet allow univocally identifying the factor of conversion between heat and work because said factor also depends on the absolute temperature in degrees Kelvin. But it is possible to evaluate the energy output of heat in mechanical units. R. Clausius, who performed this calculation, adopted the subterfuge of introducing a new function of state instead of heat. This, being integrable, allows writing the energy balance between the initial and final states. Entropy without statistical significance is just that function of state which allows writing the heat absorbed per cycle by all thermal machines in mechanical units, i.e. in joules. [9] Replacement of heat by entropy in balance calculation implies a conceptual abstraction even at the level of that which is imagined to be transferred between two bodies at different temperatures. As temperature increases, another mode of exchange of the heat substitute progressively appears, the mode called radiation. This mode, just as heat conduction and its production by friction between mechanical parts in movement, is excluded from Carnot’s cycle balance (reversible) [16]. For mechanical purposes it enters as a reduction of output. Despite the “Kirchhoff cycle” having null efficiency, he behaved as though Fermat’s principle for optics allowed evaluating the mechanical equivalent of radiation. Even if we leave out of consideration the question of the unit of measure, it is not possible to calculate dissipated energy by leaning on thermodynamic states. As a matter of fact, this has been known for some time because the spectral lines of gaseous emission are typically associated with quantum jumps between given energy levels. But this is only a half solution.

[16] If instead heat is assimilated with a fluid, the principle of conservation of heat is independent of the fact that heat produces work. Every mechanical interpretation of heat upstream of the dissipation problem would do.
Indeed, it is clear that the representation of a transition cannot derive from the most meticulous study of the stability of the levels mentioned provided that the transition in question does not occur. As an example, if illumination whitenes a coloring agent, the study of the chemical properties of the coloring agent before and after the reaction is different from that of the velocity of reaction as a function of illumination. But this is half the solution. Indeed, we even judge as valid the interpretation of the associated emission as a mere signal. To be fair, and irrespective for a moment of the particular structural conjecture associated with the spectrum, all the chemistry based on spectral analysis identifies the substances by "fingerprinting".

Recapitulating, in classical thermodynamics, whether an absolute temperature is admitted or not, the hypothesis that the processes can pass through states all of equilibrium contains the designation of the thermodynamic states. Hertz himself admits at least that assigning an energy state in mechanics has sense. To give a meaning to "non-mechanical" energy, he calculates the balance between states in which slowly variable electrical magnitudes are balanced everywhere in "physical space"\footnote{This approach, and hence its energy interpretation, fails if electrical measurements replace mechanical ones. Indeed, Hertz uses mechanical forces to balance unknown electrical quantities, not to establish once for all an electromechanical equivalent.} by mechanical forces. If radiation occurs during the process, the radiant energy is not balanced but, Poynting’s result for electromagnetism being valid, Hertz can hypothesize that radiation is transformed into heat by the Joule effect. Planck extends the balancing method to the dipole antenna (Hertzian oscillator), feigning that it would be possible to assimilate it with a mechanical oscillator. Planck’s oscillators thus represent the mechanical counterpart which balances electromagnetic radiation (stationary). Admitted that it would be admissible to mediate (in the sample space) the energetic effect of electromagnetic oscillations on an oscillator, Planck considers that, at equilibrium, radiation is balanced on average. But an averaged oscillation is not at all periodic. Besides, conclusions about statistical populations of oscillators are not drawn in the space where bodies move, which for Hertz is precisely physical space. For lack of the mechanical balancer, Planck does not immediately represent an energy according to Hertz and therefore cannot assert that his formula represents a distribution of energy localized in the cavity of the oven and express it in joules. To be able to localize electromagnetic energy in space, irrespective of the velocity at which electrical magnitudes change, it is necessary to assume Einstein’s space-time concept. Below, we are setting forth three points which in our opinion make the energy interpretation of the equations of electromagnetism problematic nevertheless.

Einstein’s developments consist of this. Concomitantly with the principle of equivalence of mass and energy, Einstein postulated in 1905 that the expressions of the electromagnetic forces do not depend on the system of reference \cite{einstein:1905}. In formulas, provided again that positive charges in motion generate neutral electrical current and putting the speed \( c = 1 \), he postulated that geometrical transformation of the frame

\[ \sqrt{\left(\frac{\epsilon_0\mu_0}\right)} = 1 \]
3 THE QUANTUM ENERGETICS INTERPRETATION

from \( \mathbf{E} = 0, \mathbf{H} \) magnetostatic to \( \mathbf{E} = \mathbf{v} \times \mathbf{H} \rightarrow \partial \mathbf{H}/\partial t \) transforms an integral frame with a charge in slow motion into one integral with the magnet in which a force \( \mathbf{F} = e(\mathbf{v} \times \mathbf{H}) \) acts on the charge (deflection of the electrical charge due to the effect of movement of the magnet at velocity \( \mathbf{v} \)). Instead, transformation from \( \mathbf{H} = 0, \mathbf{E} \) electrostatic to \( \mathbf{E} = -\mathbf{v} \times \mathbf{E} \rightarrow -\partial \mathbf{E}/\partial t \) transforms the frame integral with a magnetic needle into the one integral with the charge in motion in which the needle point is subject to the force \( \mathbf{M} = -\mathbf{I} \times \mathbf{E} \) (deviation of the magnetic needle point due to the effect of a current of charges of velocity \( -\mathbf{v} \)). Because of the principle of equivalence, the field variables also have an energy interpretation for the microsystems and these correspond to geometric points or infinitesimal volumes. But before 1905 no one had ever asked that the diagrams of which thermodynamics makes use to represent energy processes enjoy some property of kinematic invariance. Indeed, the Galilean invariance principle established independence from position and velocity only for the laws of dynamics. Furthermore, a limit was set for the smallness of the systems to which thermodynamics is applied. Indeed, accurate determination of the mechanical equivalent of heat had required the availability of industrial means (Rumford, Hirn, Joule).

The first problematic point arises if we want to distinguish “physical space” from the space-time diagrams of which classical mechanics makes use. Admitted that the relations indicated by Einstein represent Faraday’s electromagnetic induction and Maxwell’s displacement current in Ampère’s equation respectively, the invariance of Maxwell’s equation system involves mechanical transformation properties of the fields at small velocities. These transformation properties are by no means shared by “physical space”. Again, the uniformity and isotropy prescribed for temperature radiation in the oven cavity do not coincide with a superposition of stationary waves in space-time.

The second problem is that, because of the principle of equivalence, the position-time graphs of motion take on the same explicative value of the more usual (in thermodynamics) indicator diagrams. In a word, in the new representation the electromagnetic field energy variables depend on velocity in accordance with the principle of relativity (Einsteinian relativity) without it being clear whether the arguments \( x, y, z \) and \( t \), of which they are in turn functions, are to be considered thermodynamic potentials or whether they are indices of position in bodies not uniformly heated as Fourier used them to describe the diffusion of the caloric. Like Hertz, Fourier described in the “physical space” the mechanical aspect of a phenomenology while in thermodynamics usually the indices are thermodynamic parameters. This is not the place to discuss which domain it would be appropriate to assume for \( x, y, z \) and \( t \) in the Maxwell equations.

The third problematic point of Einstein’s interpretation is the following. Until now we have identified radiative, electric et cetera phenomenology with the assigned mathematical expressions of the electromagnetic fields. Therefore, the expressions of the fields in empty space could already be considered equivalent to thermodynamic potentials. Instead, this is not quite correct because the equations with partial derivatives of which the fields are solutions establish only
the dependence between variations and do not allow specifying functional expressions. But the fields in vacuo are obtained, for the mathematical theorem of existence and uniqueness of the solutions of differential equation systems, when the initial and boundary conditions are specified. Then the question is, how to obtain non trivial solutions. Indeed, assumed the relativity principle, and given the mathematical expression of an electromagnetic field, it is understandable that it does not reach thermodynamic equilibrium unless dissipation did not characterize that solution initially. In a word, for purely mathematical reasons, no solution of Maxwell’s equations satisfying boundary and initial conditions, and not corresponding to “blackbody radiation” initially will merge with it at the end of all the transients.

In conclusion, the premise for interpreting electromagnetic fields as local energy perturbations in space and transport of electrical charges is that the arguments $x, y, z$ and $t$ take on a single meaning for all the theories involved and possibly that of coordinates of “physical space”.

3.3 **Description of the electrical signal (received) (***

In this paragraph we shall again take up the clarification of Maxwell’s equations undertaken by Hertz and got beyond by Einstein. Electromagnetism is a descriptive theory. Indeed, the system of the four partial differential equations stylizes as many key experiments of Faraday, to wit electrostatic induction, absence of magnetic monopoles, electromagnetic induction [14] and “unipolar motor”. It doesn’t seem to be a physics theory because Maxwell didn’t clarify which of the solutions are elementary. Or better, he proposed the analogy with light transmission for the propagated solutions but without saying which characteristic of light he imagined represented by $E$ or $H$. Since the same theory includes the oldest conceptions of electrostatics and magnetostatics and it seems to make possible a unified treatment of them, the meanings attributed to the variables from the older theories were automatically accepted. Thus, experimental verification of the "existence" of Hertzian waves, instead of broadening the class of signal-solutions, favored the extension from electrostatics to electrodynamics of the mathematical magnitudes $E$ and $H$ (forces), and $D$ and $B$ (polarizations). Therefore, in writing the overall mechanical and thermal energy balance for those magnitudes, Hertz attacks the problem of determining the mechanical equivalent of the electromagnetic theory [15].

In the first place, he shows how, if desired, it is possible to take the equations of Maxwell from the potentials taken from the rival theory. His procedure consists of balancing with a system of electrical and magnetic forces the electrical and magnetic current variations that result because of mutual dependence on mathematical expressions. [16] Obviously, he assumes that effective electrical magnitudes correspond to the mathematical corrections. He calculates by the induction principle (mathematical) the corrections necessary at each successive order. The procedure allows expanding in power series the forces and therefore the potentials from which they derive. The expansion in series of the potential function satisfies a wave equation and in addition allows taking the equations of
electromagnetism in a quite immediate manner (as regularity conditions). But it is not possible to make reflections on the (mechanical) work carried out by the electrodynamics system because it is always balanced electrically.

In the second place he chooses as fundamental the experiment of Oersted, of the torsion of a compass needle near a battery-powered electric circuit, an effect analogous to that caused by a magnet. It ensues that the same mechanical effect can be caused either electrically or magnetically. Therefore the formula: 

\[
(4\pi/c)I_0 = \oint H \, dr
\]

is interpreted as though it linked together the measured value of the electric current and that of magnetomotive force. For the behavior to be perfectly symmetrical, it would be necessary to observe an electrical effect of the magnets or even a mutual interaction between solenoids traveled by a direct current. In actual fact, Faraday observed that the abrupt movement of a conducting loop near a magnet produces an electric shock at the clamps of the circuit. In formula:

\[
(1/c)\frac{\partial H}{\partial t} = -\text{curl} \mathbf{E}
\]

An effect that, according to Lenz, expresses an energy principle of homeostatic conception applied to Oersted’s current.

Hertz’s thermodynamic interpretation of electromagnetism depends on the hypothesis that the heat developed by the conductor is an integral part of Oersted’s observation i.e. on the assumption that the electromagnetic magnitudes defined by the equations show some properties regardless of the mode of detection. If the Faraday effect is the equivalent of Oersted’s experiment valid for variable fields, part of the electrical energy of the current must necessarily be dissipated in heat (in erg/second) even in induction. In 1843 Joule had excluded that heat development was linked to induction; the latter appeared nevertheless linked to the resulting current increase. Thus it seemed that current flow always involves heat development. Today, on the contrary, we know that electric ”current” in a solenoid is detectable with Oersted’s needle under conditions in which heat is not developed . Under these conditions we cannot associate

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19Maxwell num. 535. Vol. II. If the magnet M is replaced with a solenoid the variation in the movement of the conductor N also alters the current in the solenoid (M). It is clear, but we write it, that if the magnet can be replaced by a conductor, at the ends of which the current can be measured, the distinction between conductor-magnet M and conductor-circuit N is artificial, hence the case record is only apparent. In addition, Newton’s third law plays no role. Indeed, as the symmetry between circuit N and magnet M is the consequence of varying only the current in one of the two conductors (M or N indifferently), induction takes place as the only effect. Faraday’s induction is at the base of electromagnetic transmission and reception.

20Maxwell used Oersted’s experiments to eliminate the magnetic hysteresis from all the linear treatment of electromagnetism. Consequently, those facts are contained in the equations. But they are not expressed in the so-called Ampère-Maxwell equation. Indeed, the latter describes the experiment of Faraday’s unipolar motor, termed later “rotating field” by G. Ferraris.

21With superconduction the torsion of the magnetic needle is observed without accompanying heat. The process of “creation” of the magnetostatic field of the superconductor according to electromagnetism is in relation with the Faraday effect described by the integral of \( \frac{\partial H}{\partial t} \) for the current which varies between closing of the circuit, \( I = 0 \) and stationary \( I_0 \) at which the potential difference at the ends of the solenoid vanishes (then \( L = \Phi/I_0 \)). In classical thermodynamics the process in which a material is transformed from (bad) conductor to superconductor is linked to the heat variation produced by the Oersted
with current energy (in mechanical units) dispersible in heat due to the Joule effect. But this mechanical contribution $jE$ is what allows interpreting in energy terms all of the expression in the field variables, to wit:

$$\frac{d}{dt}(1/8\pi \iiint (E^2 + H^2) dV) + c/4\pi \iint (E \times H) \cdot n dS = - \iiint jE dV$$

integrated on a volume $V$, on the boundary surface $S$ of which the electrical and magnetic forces do not vanish, without identifying the induced current with that obtained by Neumann $^{22}$. $^{19}^{20}^{21}$ Dropping the energetic interpretation of electromagnetic fields, there is no reason to think that the energy is saved or dissipated by induction. There is nothing counterintuitive in this interpretation; it is merely a matter of accepting that induction, as it is written, links two electrical variations without fixing any mode of detection.

In conclusion, mere identification of radiant heat with an entire theory (electromagnetism) not only does not allow writing the energy involved in the process of emission at equilibrium but even makes the subsequent development of thermodynamics incoherent. As to identification of black radiation with an observed phenomenon – a problem totally outside of mathematics – the first fine distinctions are surely prior to the theorem of Kirchhoff.

4 Spectral distribution as the receiver’s response

In the preceding numbers we glanced at different formalizations of light phenomenology. Each of them answers certain requirements. In the past, it was not usual to make distinctions because it was not usual to think that mathematics is a language capable of representing even ideas in mutual disagreement. In addition, it was assumed that energy principles had a universal significance or it was even believed that they were automatically satisfied by any faithful description of nature. However that may be, "verification" of the predictions concerning radiant heat implied demands at the experimental level. One of these demands concerns the spectral characterization of radiation at equilibrium in the cavity of the oven (possibly electrically heated). The reason for this demand, strictly experimental, is to be sought in the fact that spectral analysis aimed at identifying chemical substances became popular at the same time. The principles of thermodynamics did not prescribe a particular spectral form for the black substance. Can they justify it when the experimenters find a credible one?

We propose the following two considerations.

i. Not only the emissions of rarefied gasses apparently depend on the chemical constitution thereof but condensed matter also has characteristic emissions.
Calling temperature radiation "black", practically all shades of "gray" are observed instead of it. Nor is it certain that the spectral form defined at the end of 1800 by the experimenters for the empty cavity of the oven at temperature $T$ and attributed to black radiation is that of thermal equilibrium. Indeed we know that in the cavity of a device which selectively amplifies radiation the spectral composition of radiation at steady condition is different. Each of the experimental spectral forms is credible, but how many thermodynamic principles do we need to show the necessity and sufficiency of all?

Electromagnetism in turn does not explain the mechanism with which radiation of the sun takes place, or what sets off the lightning process, or what causes the luminescence of the firefly’s glow. But the receiving and transmission modes according to Faraday and Hertz allow receiving them all and often attributing each of them to a specific transmitter. Thus, the theory after Faraday’s experiments portrays as electromagnetic signals all of solar radiation, the flash and the firefly’s glow indifferently.

Relying on these two considerations, we shall seek to explain why, according to us, the black radiation spectrum can be considered an antenna reception and can be interpreted as the receiver’s band-pass.

First of all, we believe that it is necessary to clarify what was intended by temperature radiation in the days of the crucial experiments. Says L. Graetz,[22] “It is common experience that a hot body in a cooler environment cools even leaving out of consideration conduction and convection. This cooling is called radiant heat. Calorific radiation which leaves hotter bodies heats only the absorbent bodies but not the diathermanous ones of the environment. […] It is deduced [from the velocity of reception] that calorific radiation is of the same type as light radiation. […]”.

From the passage quoted it appears that thermal emission propagates differently from electromagnetic. Indeed, it spreads at great velocity from the hotter bodies to the colder ones. Now, since the diffusion process is not endowed with directivity, assuming that radiation spreads from hot to cold bodies, it is expected to be able to measure the absolute emissive power of a body only if the detector surrounds it completely and is kept at such a low temperature as to absorb entirely any radiation. As the thermometer cannot be taken to temperature $T = 0 \, K$ in the laboratory, the problem of measuring the spread of radiant heat has been faced by using a covering kept at a temperature other than zero but very well insulated. The radiation which no longer spreads due to the absence of the thermal gradients takes the name of temperature radiation. First of all, it seems that an oven radiation is not a MASER because the radiation moves to equilibrium by diffusion instead of resonance, i.e. forming stationary electromagnetic waves[23]. Then, if there is temperature radiation, a pyrometer can measure the temperature at a distance. This means that the composition of a sample of radiation extracted from the oven, collimated, dispersed, analyzed and detected at the temperature of the laboratory is homogeneous with the spectral composition of the radiation at thermal equilibrium in the same empty oven. The external detector assigns to each frequency a characteristic intensity in accordance with a function $F(T, \nu)$. In the oven, which is empty in the spe-
specific sense that the air contained in the cavity does not heat by irradiation, being diathermanous, there is an internal detector. The internal detector, for example a bolometer, is set to measure the temperature of the oven cavity; for each value of the electric current measured there is a corresponding temperature. As the oven is empty, the internal detector attributes a single temperature to the radiation at thermal equilibrium. It cannot distinguish between their spectral components because the radiation is at thermal equilibrium and therefore all the frequency components are at the same temperature. But the external detector distinguishes the frequencies from each other because it allows assigning to each dispersed beam a different energy. Let us assume for convenience that the external detector is also a bolometer. The external bolometer measures a different electrical current for each frequency component of the black radiation impresses thereon (the laboratory air is also diathermanous). But the internal bolometer records a single current despite the radiative frequencies of the extracted sample being those of the radiation in the cavity. To us, it seems that the following circumstances are at the origin of the different behavior of the two bolometers. The body of the internal bolometer moves to thermal equilibrium with the internal walls of the oven by convection (in the meaning of the heat theory) despite the air being transparent to light. But the sensitivity of the resistance of the external bolometer depends on the particular striking spectral component in the first place because the radiation striking it was actually dispersed and, in the second place, because air at atmospheric pressure diffuses (in the optical sense) little at the so-called spectral windows.

The experimental verification, if we want to call it that, of the theorem of Kirchhoff in the case of black radiation seems to us unacceptable. Indeed, it would be a matter of taking the measured value of the emissive power for each wavelength back to the same instrumental sensitivity and so on for all the wavelengths actually irradiated by a cavity, however heated. But it is not necessary to know the emission band of the oven cavity to verify the theorem because this instruction is not in the terms. On the contrary, the theorem prescribes for the ideal blackbody the property of absorbing all the radiation regardless of temperature and wavelength, that is \( A_S \equiv 1 \) where \( A_S \) is the absorption power of the blackbody. According to Kirchhoff, the emission of said blackbody must be proportional to absorption. Considering the fact that the property for the other bodies is given by a biratio, i.e. \( E/A = E_S/A_S \), temperature being fixed, it can be put \( E_S \equiv 1 \) where \( E_S \) is the emissive power of the blackbody. From the experimental verification of the theorem, with the correction for sensitivity, it might prove to be that not even the oven cavity is an ideal blackbody.

Rather than doing that, we are interested in pointing out that, whatever the manner in which the oven produces radiation and whatever be the homogeneity of distribution of the intensity in the cavity, the technique of detection is the one used in telecommunications. That is, radiation with the characteristics of electromagnetic radiation propagation is detected. For this reason, allowance can be made for the sensitivity of the instruments by introducing the band-pass reception concept. Now we shall seek to make plausible that, given a body
emitting with the mode hypothesized by Kirchhoff for the blackbody, the spectral form observed would be exactly the band-pass of the receiver. Indeed, let $E/A = \eta_\lambda \equiv F(T, \lambda)$ where $E$ and $A$ are the relative emissive and absorption power respectively of any body $C$ at temperature $T$ and wavelength $\lambda$. Therefore, $E/A = 1 \cdot \eta_\lambda(T, \lambda)$ where $\eta_\lambda$ or better $\eta_\nu(T, \nu)$ encodes the spectral response of the receiver. This is universal when the measuring instrument is assigned. But if the reference body is one of those which are usually called black without being black, i.e. if there isn’t any temperature radiation, then the spectrum of the body obtained using a “black detector” would be $E_G/A_G = \epsilon_G(T, \nu)$ while the spectrum actually recorded is the product of the irradiation of the body with the response in frequency of the receiver, i.e. $E/A = \epsilon_G(T, \nu) \cdot \eta_\nu(T, \nu)$ where $T$ is a frill because:

1. the external detector is not at thermal equilibrium with the oven, and
2. the radiation detected is not that of the blackbody.

## 5 Summary and Conclusion

We have sought in this work to expose why we think that formulating in classical thermodynamics the hypothesis that radiant heat is electromagnetic is of no use in accounting for either the distribution of energy of the blackbody or the irreversibility of the thermodynamic processes. As regards the first aspect, we have shown that temperature emission at thermal equilibrium does not depend by definition on the characteristics of the transmitter. But in the electromagnetic representation, irradiation depends on the initial and boundary conditions. As far as the second aspect is concerned, we have tried to clarify that thermodynamics and electromagnetism are different theories that respond to different requirements. It is possible to trace diagrams in classical thermodynamics but they do not depend on kinematic parameters, that is to say on spatial and temporal variables. But electromagnetism has been designed to enjoy the properties of invariance associated with movement in geometry. Although conduction, convection and radiation make the thermal machine cycle irreversible, the electromagnetic representation of transport phenomena does not account for irreversibility. Contrariwise, the emissive properties of the blackbody according to thermodynamics being assigned, analysis of the signal received allows concluding that the spectral form observed agrees with the receiver’s band-pass.

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