Hidden Variables: The Resonance Factor

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ABSTRACT

In 1900 Max Karl Planck performed his famous black-body radiation work which sparked the quantum revolution. Re-examination of that work has revealed hidden variables, consistent with Einstein's famous sentiment that quantum mechanics is incomplete due to the existence of "hidden variables". The recent discovery of these previously hidden variables, which have been missing from foundational equations for more than one hundred years, has important implications for theoretical, experimental and applied sciences and technologies.

Planck attempted to integrate the new "*resonant Hertzian (electromagnetic) waves*", with existing Helmholtz theories on energy and thermodynamics. In his famous January 1901, paper on black-body radiation, Planck described two significant hypotheses – his well known Quantum Hypothesis, and his more obscure Resonance Hypothesis. Few scientists today are aware that Planck hypothesized resonant electromagnetic energy as a form of non-thermal energy available to perform work on a molecular basis, and that Planck's Resonance Hypothesis bridged the gap between classical Helmholtz energy state dynamics of the bulk macrostate, and energy state dynamics of the molecular microstate.

Since the black-body experimental data involved only a thermal effect and not a resonant effect, Planck excluded the resonant state in his black-body derivation. He calculated Boltzmann's constant "k_B" using completely thermal/entropic data, arriving at a value of 1.38×10^{-23} J K^{-1} per molecule, representing the internal energy of a molecule under completely thermal conditions. He further hypothesized, however, that if resonant energy was present in a system, the resonant energy would be "*free to be converted into work*".

Planck seems to have been caught up in the events of the quantum revolution and never returned to his Resonance Hypothesis. As a result, a mathematical foundation for resonance dynamics was never completed. Boltzmann's constant was adopted into thermodynamic theories without its natural companion, the resonance factor ("r_f").

Keywords: Planck, Boltzmann's constant, Resonance, Resonance factor, Helmholtz energy

1. INTRODUCTION

Boltzmann's constant is incomplete. It is missing its resonance factor. The Boltzmann constant describes the internal energy of a single atom or molecule, based solely on its temperature, and was described by Max Planck in his famous black-body radiation paper. That work contains Planck's description of the black-body equation, his Quantum Hypothesis, the quantum formula, $E = h\nu$, Planck's constant "h", Avogadro's number, and Boltzmann's constant "k_B". Although Planck was the first to derive and calculate the Boltzmann constant, his heavy reliance on Ludwig Boltzmann's statistical mechanics resulted in the constant being named after Boltzmann. Many scientists are familiar with Planck's   spectacular accomplishments in his landmark work, and of the fact that it sparked the entire quantum revolution.

Far fewer are familiar, however, with Planck's Resonance Hypothesis which he proposed in that same paper. In the five (5) years leading up to his black-body radiation work, Planck tried to integrate the recently proven "*resonant Hertzian (electromagnetic) waves*"[1] with existing theories on energy and thermodynamics. He developed a Resonance Hypothesis in regards to electromagnetic waves and described it briefly at the beginning of his black-body paper.[2]

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However, since the black-body experimental data involved only a thermal effect and not a resonant effect, Planck devoted the remainder of his paper to derivations based *solely* on non-resonant, thermal effects. When Planck derived the Boltzmann constant in his famous black-body paper, he excluded the resonant state and calculated k_B without its natural companion, the resonance factor ("r_f"). Subsequent use of the Boltzmann constant without its resonance factor led to the isolation of thermodynamic theory from the realities of many systems in science and industry.

To understand this remarkable state of affairs, one must look back in time beyond Planck, to the 1600's and the work of Galileo Galilei. Around 1602, Galileo began investigating the pendulum as a device for measuring and keeping time. When Galileo gave small taps to his pendulum, exactly timed to match the frequency of the pendulum swing, its swings grew larger and larger (Fig. 1 below). Galileo had discovered the basis of resonance. Resonance occurs when the frequency of an applied vibration, motion, or energy matches the natural frequency of a system, and the amplitude of the system's vibrations increase in response.
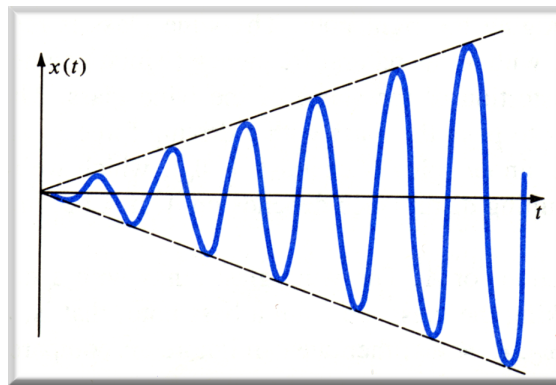

Figure 1. Resonance and oscillation amplitude as a function of time.[3] Galileo discovered this phenomenon by giving small taps to his pendulum, which matched the frequency of the pendulum's swings. The pendulum oscillations grew larger and larger even though his taps were very small.

At about the same time that Galileo was performing his research with the pendulum, the remarkable French mathematician, Pierre de Fermat, was born. He is best known for his work on number theory, probability, and Fermat's principle of optics. What is less well remembered about Fermat is that he developed the first *equation* for resonance. The resonance curve produced by his equation demonstrated that as the rate of a mechanical vibration (e.g., a tap) neared the natural vibratory rate of a body (e.g., the swing of a pendulum), the amplitude of vibrations in the body increased.

About twenty years later, famed English scientist, Sir Isaac Newton, published his three laws of motion. From his second law – force equals mass times acceleration - another resonance equation was derived:

$$A = \frac{a}{\left| v^2 - v_o^2 \right|} \tag{1}$$

where "A" is the amplitude of the system's oscillations, "a" is the acceleration in the system's oscillation caused by the force of the outside vibrations, "v" is the resonant frequency of the system, and "v_o" is the frequency of the outside vibrations that are applied to the system. As the frequency of the outside vibrations nears the resonant frequency of the system, the denominator in Eq. 1 becomes *very* small. Even for small accelerations "a" (e.g. small taps), dividing by a *very* small number produces a large amplitude (Figure 2. below).
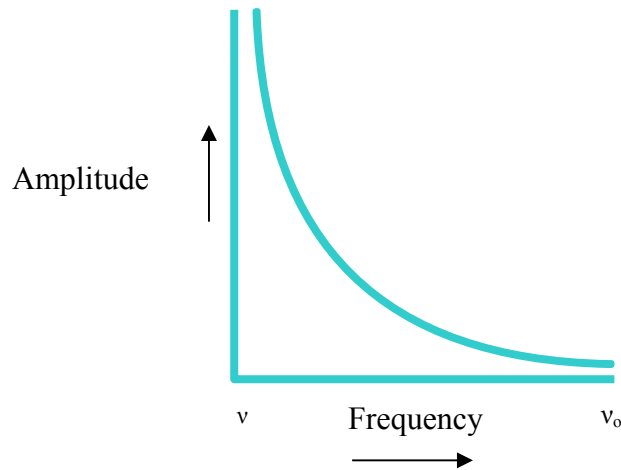
Figure 2. Amplitude plotted as a function of an applied resonant force. As the outside frequency "ν_o" approaches the resonant frequency "ν", the amplitude of the system's oscillations increases dramatically.

In 1748, the Italian mathematical prodigy Maria Gaetana Agnesi described Fermat's resonance curve in greater detail in her book on integral calculus and differential equations. The book was widely translated throughout Europe and caused such a sensation, that Pope Benedict XIV appointed her to the mathematics chair at the University of Bologna. The idea of resonance and the mathematics to describe it, became widely known and accepted as a scientific principle.

A century later, famed German physician and physicist Hermann von Helmholtz explored concepts of both resonance and energy. As a youth, Helmholtz had a great love of the natural sciences. His father arranged for him to attend the royal medical school, where he would receive free tuition in exchange for service in the army. Upon graduation Helmholtz became a Hussar-Surgeon, and set up a small laboratory in his barracks. There he conducted experiments on muscle metabolism, heat, nerve conduction and electromagnetics, which were published by the newly founded Berlin Physical Society. Helmholtz believed that different energies, such as heat, mechanical, electrical, magnetic and chemical, were the "*definite equivalent of one and the same energy, whatever the mode by which one [energy] is transformed into another*".[4]

Helmholtz became engaged to be married, but there could be no wedding until he obtained a permanent position. This domestic exigency induced Helmholtz to write his famous 1847 treatise on the conservation of energy.[5] Helmholtz's treatise provided the first good mathematical description of the conservation of energy. He showed that the many different forms of energy are interconvertible, "*…heat, electricity, magnetism, light, and chemical affinity … from each of these different manifestations of [energy] we can set every other [manifestation] in motion*". The *Annalen* refused to print Helmholtz's paper, so he had it printed up privately in a pamphlet, which fortuitously had its desired effect. He was appointed Professor of Physiology at Königsberg, married, and continued his work in medicine and physics.

Helmholtz described his ideas about energy in a simple mathematical form:

$$U = A + TS \qquad (2)$$

where "U" is the internal energy of a system, "A" is the energy available for orderly work (now known as "Helmholtz energy"), "T" is temperature (Kelvin) and "S" is the disorderly entropy (or as Helmholtz described it the *opposite* of work, meaning it was the energy *unavailable* for work). He conceptualized all energy as involving motion, and differentiated between work and thermal energy based on whether the motion was uniform (work) or random (heat) (Figure 3. below).
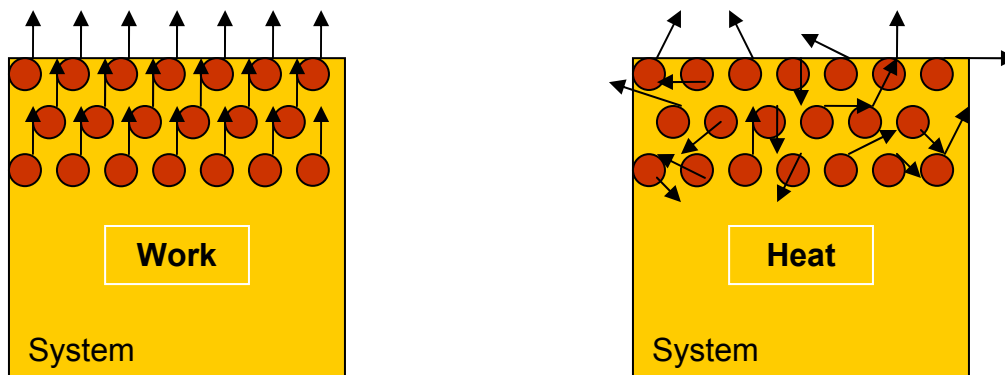
Figure 3. The Helmholtz concept of energy involving motion. Work: the transformation of energy that makes use of the <u>uniform</u> motion of atoms, and is available to perform work on a system. Heat: the transformation of energy that makes use of the <u>random</u> motion of atoms, and is unavailable to do work.

Moving to the University of Bonn in 1855, Helmholtz began his investigations on sound and the physics of hearing. In 1862 his book on acoustics was published, and in the section on resonance he explained resonance and sympathetic resonance:[6]

> "*<u>sympathetic resonance</u>. This phenomenon is always found in those bodies which when once set in motion by any impulse, continue to perform a long series of vibrations before they come to rest. When these bodies are struck gently, but periodically, although each blow may be separately quite insufficient to produce a sensible motion in the vibratory body, yet, provided the periodic time of the gentle blows is precisely the same as the periodic time of the body's own vibrations, very large and powerful oscillations may result. But if the periodic time of the regular blows is different from the periodic time of the oscillations, the resulting motion will be weak or quite insensible.*
>
> *Periodic impulses of this kind generally proceed from another body which is already vibrating regularly, and in this case the swings of the latter in the course of a little time, call into action the swings of the former. Under these circumstances we have the process called <u>sympathetic oscillation</u> or <u>sympathetic resonance</u>.*"

By the 1870's Dr. Helmholtz's brilliant interdisciplinary work had distinguished him to such an extent that he was appointed the Chair of Physics at the University of Berlin (the highest physics position in all of Germany at that time). There he lectured students, including the young Max Planck and the brilliant Heinrich Hertz (who received his physics doctorate *magna cum laude* in only two (2) years) on conservation of energy, resonance and other topics. A keen experimentalist, Helmholtz subsequently challenged Hertz to prove experimentally the existence of Maxwell's theoretical electromagnetic waves.[ii] So great was Helmholtz's love for experimentation, that one of his conditions for even accepting the Physics Chair in Berlin, was the construction of the Physikalisch Technische Reichsanstalt ("PTR") – the experimental physics institute where the black-body radiation experiments were carried out two (2) decades later.

2. THE BLACK-BODY RADIATION EXPERIMENTS

Black-body radiation is the light emitted by a perfect light absorber (i.e., it is black), and the intensity and wavelength of the light naturally emitted by the black-body material changes as its temperature changes. Black-body radiation devices were the super-colliders of their time, and Planck, who by the 1890's was a Professor of Physics at the University of Berlin, had ready access to the data generated from the black-body device at the PTR. Black-body devices were, paradoxically, entirely white on the outside, so that they could reflect light. The device had an inner chamber (c_1)

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ii   Hertz succeeded and in 1888 published his electromagnetic wave work, after measuring both the length and velocity of the waves and showing that radio waves were composed of the same type of energy as visible light.

lined with the natural black-body material graphite and a second outer chamber (K) which could be filled with either ice or steam (Figure 3). After the graphite chamber reached equilibrium at either 0° C (273° K) or 100° C (373° K), the shutter (V) in the chamber was opened allowing the emitted black-body radiation to exit through the opening (O_1) and the aperture (D), to be measured by the bolometer (B) as a function of time (Fig. 4, below).[7] Scientists at the PTR were gathering data to develop a mathematical description of the changes in the black-body light emissions based on changes in its temperature. Importantly, no light was allowed to enter the inner chamber of the black-body device, so that the experimental data it produced would be based solely on thermal changes in the inner chamber.
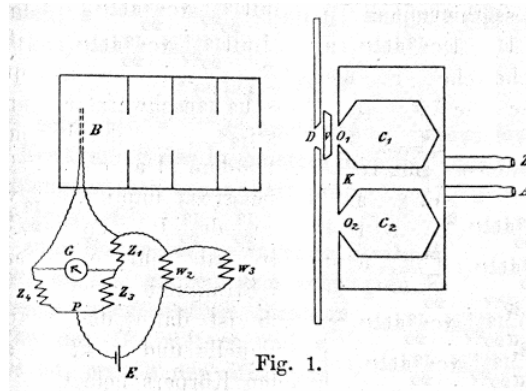

Figure 4. Schematic of the black-body device used by Ferdinand Kurlbaum at the PTR, to make black-body measurements. In 1898 Kurlbaum found that the black-body radiation from the chamber at 100 ° C was 0.0731 watts/cm^2 more, than when the chamber was at 0 ° C.

3. PLANCK'S CALCULATION OF BOLTZMANN'S THERMODYNAMIC CONSTANT

Planck (as well as the other physicists of his time) was very aware of the fact that the black-body device produced only thermal-based data. This understanding appears as an assumption that the energy of the black-body material depended only on its temperature:[2]

"the law of energy distribution in the normal spectrum is completely determined when one succeeds in calculating the entropy S ... as a function of its vibrational energy U. Since one then obtains, from the relationship dS/dU = 1/T, the dependence of the energy U on the temperature T ... [dU = T dS]".

Planck's approach to the black-body problem, was that the energy of the black-body's radiation depended solely on its temperature and entropy, which, according to Helmholtz meant the motion was completely disordered and random. This understanding, that the thermal/entropic black-body data was the result of purely random disordered motions, allowed Planck to adopt Boltzmann's statistical mechanics in his black-body derivation. Boltzmann's statistical approach was based on the assumption that all the elements (e.g., molecules) in a system were moving randomly and in a completely disordered manner. Since the random disordered motion of the molecules depended solely on their temperature, the probability of individual energy states and their distribution could be calculated based solely on temperature. Planck incorporated these ideas in his preamble:

"§1. Entropy depends on disorder and this disorder, according to my [Planck's] electromagnetic theory of radiation ... depends on the irregularity with which it constantly changes its amplitude and phase ...If amplitude and phase both remained absolutely constant, which means completely homogeneous vibrations, no entropy could exist and the vibrational energy would have to be completely free to be converted into work."

Planck had attended the lectures of Helmholtz as a student, and had learned that the total internal energy of any system is the sum of its orderly work energy, and its disorderly, thermal/entropic energy, "U = A + TS". At one end of the spectrum there could be a totally random disordered state in which the internal "*energy U [depends solely] on the*

temperature… [and] the entire problem is reduced to determining [entropy] S as a function of [energy] U".   In other words, since U = A + TS, and A = 0, then:

$$U = TS \qquad (3)$$

The black-body device was purposely designed to measure *only* the effects of temperature, and so Planck was describing what was well known at the time. Entropy depends on disorder and by definition, describes the energy *unavailable* for work. The Helmholtz work energy depends on order, and describes the energy that *is available* for work (Fig. 3 above). In the case of the light emitted by the black-body material, the total energy of the system could be calculated based solely on its temperature because the Helmholtz energy ("A") was, by experimental design, equal to zero. This allowed Planck to calculate the Boatman constant "k_B", for the average energy of a single molecule, based solely only its temperature, using the relationship, U = TS. It was not necessary for Planck to consider the Helmholtz work energy in his black-body radiation equations, because it had been excluded from the system.

The Boltzmann constant thus does not consider the orderly work energy in a system either. The Boltzmann constant was calculated by assuming that the Helmholtz work energy was equal to zero. If Helmholtz work energy is present in a system and absorbed by its molecular elements, the Boltzmann constant cannot be used to describe the total energy of that system or of its elements. It can be used to describe only that portion of the internal energy of the system or element, which is contributed by the temperature and entropy inherent to the system. The Boltzmann constant allows one to calculate the *minimal* internal energy of a system or molecule, but not the total energy when Helmholtz work energy is present. As such, the Boltzmann constant functions as a baseline proportionality constant.

To describe the molecule's *total* internal energy, the additional energy in the system due to the Helmholtz work energy must be accounted for. Planck's Resonance Hypothesis laid the foundation for doing just that.

4. PLANCK'S RESONANCE HYPOTHESIS

Planck's contributions to the quantum sciences are well known and his quantum formula (E = hν) sparked the whole quantum revolution. Little attention has been paid, however, to his Resonance Hypothesis – namely, the idea that when resonant electromagnetic energy is absorbed by an element or molecule in a system, the "*energy would have to be completely free to be converted into work".* The distinguishing feature that determines whether the light will be converted into actual work energy or into simple disordered heat energy, is the frequency of its oscillations and the degree of resonance between the light's oscillations and the oscillations of the elements in the system. For example, if the electromagnetic oscillations are "*absolutely constant …[and] completely homogeneous",* i.e., resonant, they will be "*completely free to be converted into work.*" Planck characterized the non-resonant electromagnetic energy by "*the irregularity with which it constantly changes",* deftly paraphrasing Helmholtz's well-known description of non-resonant energy, i.e., when "*the periodic time of the [energy oscillations] is different from the periodic time of the [molecule oscillations].*

Referring again to Planck's preamble (§1. above), Planck indicated that he had integrated his own recently developed electromagnetic theory,[8] with Helmholtz's ideas on conservation of energy and the total internal energy of a system. Planck elegantly assimilated Helmholtz's concepts regarding the effects of work energy at the bulk (or macrostate) level, with the effects of resonant electromagnetic energy at the molecular (or microstate) level. A closer reading reveals that Planck compared and contrasted the total entropic state with the total resonant state. In the latter case, he described a system consisting of "*completely homogeneous vibrations"* in which "*no entropy could exist".* In other words, Planck was suggesting that according to the well-known relationship, U = A + TS, if S = 0, then:

$$U = A \qquad (4)$$

Having described resonant electromagnetic waves as orderly and "*completely homogenous vibrations",* Planck then linked that concept to Helmholtz's teachings, stating that the "*energy would have to be completely free to be **converted into work**.*" This was Planck's insightful Resonance Hypothesis.

Planck made the important connection between the effects of ordered work energy at the bulk or macrostate level, and the effects of ordered and resonant electromagnetic work energy at the molecular microstate level. He thus formalized the concept of "*resonant Hertzian waves*" (resonant electromagnetic energy), as a form of non-thermal

energy available for work on a molecular basis and in a system. This long neglected concept embodied by Planck's Resonance Hypothesis, may be even more revolutionary than his quantum hypothesis.

Although Planck's Quantum Hypothesis garnered all the attention in the past, this may now be the century of Planck's Resonance Hypothesis. Widespread use of optical, photonic, and electromagnetic technologies has led to many experimental observations which cannot be explained by existing quantum or thermodynamic theories. Planck's Resonance Hypothesis provides a potential mechanistic explanation. Since the resonant energy is free to be converted into work, the application of resonant energies can produce effects not typically seen under purely thermodynamic conditions. Indeed the fields of photochemistry and photobiology unknowingly relied on Planck's Resonance Hypothesis.

Planck's hypothesis and the effects of resonant energies go far beyond these fields, however. His revolutionary resonance concept has been confirmed in a wide variety of systems and phases – solid, liquid, gas, plasma, biologic, organic, inorganic, electrical, magnetic, chemical, materials, and crystalline – and these effects span the entire electromagnetic spectrum.[9-16] Results range from accelerated growth of plants and animals, to enhanced chemical catalysis, increased crystal nucleation, virtual thermal effects, and resonant phase changes. In accordance with Planck, when the "*resonant Hertzian waves*" induce Helmholtz's "*sympathetic resonance"* in a system, the energy is "*free to be converted into work"* and "*very large and powerful oscillations may result"*.

Although Planck introduced his prescient Resonance Hypothesis, he never fully developed it the way his Quantum Hypothesis was developed. That task falls to the current generation, and an initial step in that direction has been taken with the introduction of the resonance factor, "r_f".

5. DERIVATIONS AND CALCULATIONS

§ 1. Derivation of the Resonance Factor

The resonance factor is the ratio of internal energy in a resonant system or element, to the internal energy of its non-resonant counterpart system or element, in a state of complete entropy.

Applying Planck's model for completely random motion, in the non-resonant system all of the internal energy is thermal, and $U_T = TS$. The internal energy per molecule in the thermal system ("U_{Tm}") is the product of Boltzmann's constant and temperature, $U_{Tm} = k_B T$. (This was the type of system modeled by Planck in his black-body radiation paper.) If ordered work is performed on the system, excluding all entropy what-so-ever, then the internal energy in the system is equal to the Helmholtz energy.

In between these two oppositely idealized black and white systems, lay an infinity of systems in shades of grey, in which ordered work is performed on the system, yet not *all* oscillations in the system are "*completely homogeneous*". A combination of *both* ordered resonant energy and disordered thermal energy are present, and the internal energy in this mixed-resonant system ("U_r") is $U_r = A + TS$. Since $A > 0$, then mean resonant internal energy per molecule ("U_{rm}") is greater than mean thermal energy, $U_{rm} > U_{Tm}$, and thus mean molecular energy is greater than the product of Boltzmann's constant and temperature, $U_{rm} > k_B T$.

Introduce a variable ("r_f") denoting a resonance factor, so that the total internal energy per molecule in the resonant system "U_{rm}" is set equal to, $r_f k_B T$:

$$U_{rm} \equiv r_f k_B T \tag{5}$$

The ratio of mean molecular energy in the resonant system to that in the thermal system is given by:
$$U_{rm} / U_{Tm} = r_f k_B T / k_B T = r_f \tag{6}$$

Since the mean internal energies of the molecule and the system are proportional (i.e., by Avodagro's number and the number of moles) the resonance factor is also equal to the ratio of resonant and thermal system energies.

$$r_f = U_{rm} / U_{Tm} \quad \text{and} \quad U_{rm} / U_{Tm} = U_r / U_T, \quad \text{therefore}$$

$$r_f = U_r / U_T \tag{7}$$

When the system is completely entropic and the molecules or elements have not absorbed any resonant energy, then the work energy is zero, the ratio of the internal energies equals "1", and $r_f k_B T = k_B T$. The resonance factor equals "one", and the total internal energy per molecule is equal to its *minimal* or baseline value, "$k_B T$". When resonant energy is absorbed by the elements or molecules of a system, however, the resonance factor is greater than one, $r_f > 1$, and the mean total internal energy per molecule is $U_{rm} = r_f k_B T$.

§ 2. Calculation of the Resonance Factor for a Water/Solute System

The value of the resonance factor - r_f - can be determined from experimental data, based on the amount of work the absorbed resonant energy performs on the system. In other words, since the resonant electromagnetic energy is "*completely free to be converted into work*", the assumption can be made that the resonant energy *was* completely converted into work. Experimental measurement of the work energy or its effects can then provide the value of the resonance factor. For example, when water absorbed resonant electromagnetic oscillations, it thereafter dissolved more solute than water that had been kept under purely thermal/entropic conditions, even though the water in both the resonant and thermal systems had identical temperature, volume, pressure, solute and dissolution time:[17]

	Resonant System	Thermal System
Weight Dissolved (g/100ml NaCl)	26.0	23.8
Moles Dissolved (NaCl)	4.65	4.25
Heat of solution[iii] (kJ)	17.5	16.0

When salt dissolves in water, the sodium and chloride dissociate into ions. The energy for the dissociation is provided by the solution and is called the heat of solution. If the system possesses resonant work energy in addition to the thermal energy, more energy is available to dissociate the salt into ions. The heats of solution in the above systems thus provide the amount of work performed on the salt solute in each system, and:

$$r_f = \frac{U_r}{U_T} \approx \frac{17.5 \text{ kJ}}{16.0 \text{ kJ}} = 1.09 \tag{8}$$

The resonance factor "r_f" can also be calculated indirectly based on the effects from the ratios of the products in the systems, whose relative concentrations are proportional to their internal energies and heats of solution:

$$r_f = \frac{26.0 \text{ g}}{23.8 \text{ g}} = \frac{4.65 \text{ moles}}{4.25 \text{ moles}} = 1.09 \tag{9}$$

The resonant system possessed 1.09 times more energy to dissolve the NaCl than the thermal system. The electromagnetic energy was converted into work of dissolution, and more solute was dissolved in the resonant system even though the temperature, volume, pressure and dissolution time were identical in both systems.

§ 3. Calculation of the Total Internal Energy per Water Molecule

The resonance factor calculated above can be used to determine the mean total internal energy per water molecule. For the water irradiated with the resonant electromagnetic oscillations, $U_{rm} = r_f k_B T$ and $r_f = 1.09$, therefore:

$$U_{rm} = (1.09)(1.38 \times 10^{-23} \text{ J K}^{-1} \text{ per molecule})(294° \text{ K}) = 442 \times 10^{-23} \text{ J per molecule} \tag{10}$$

Under purely thermodynamic conditions, the mean molecular internal energy would be only 405×10^{-23} J. Applying the Helmholtz energy equation to a single molecular element in the system:

[iii] Heat of solution taken as 3.76 kJ/mol for the solute NaCl in liquid water.

$$U_{rm} - U_{Tm} = (A_m + TS_m) - TS_m = A_m = 37 \text{ X } 10^{-23} \text{ J per molecule}$$

(11)

The average resonant Helmholtz energy absorbed by the molecular elements in the experimental resonant water-NaCl system described above, was $37 \text{ X } 10^{-23}$ J.

§ 4. Calculation of Virtual Thermal Effect Resulting from the Resonant Helmholtz Energy

The virtual or apparent thermal effect resulting from the resonant electromagnetic Helmholtz energy can be calculated. Substitute the mean internal energy of the resonant molecule, for the mean internal energy of the thermal molecule in the equation $U = k_B T$, and solve for the temperature "T", $T = U / k_B$:

$$T = \frac{U_m}{k_B} = \frac{442 \text{ X } 10^{-23} \text{ J per molecule}}{1.38 \times 10^{-23} \text{ J K}^{-1} \text{ per molecule}} = 320° \text{ K} = 46°C \qquad (12)$$

The water exposed to the resonant electromagnetic energy behaved as though it was at 46° C, even though it was only 21° C. The Helmholtz energy provided a "virtual" or apparent thermal effect, equivalent to an increase in temperature of 25° C. Without the Helmholtz energy, the water would need to be heated to 46° C, to dissolve the same amount of solute.

6. DISCUSSION

Planck derived the Boltzmann constant "k_B" based on data from an experimental arrangement in which *all* the energy measured was due to completely thermal/entropic effects. Planck clearly recognized the dynamic balance between work energy and thermal energy, which was well known to physicists of his time (Fig. 3 above). His introduction and preamble discuss the differences between the thermal/entropic energy, which by definition, is *not available* to do work, and the resonant electromagnetic energy, which according to Planck's remarkable Resonance Hypothesis, *is available* for work (§ 1. above).

Planck probably did not introduce a resonance factor in his black-body radiation paper because it was unnecessary. The black-body device under study had been specifically designed to exclude all forms of energy other than heat. No light - resonant or otherwise - was allowed to enter the inner chamber containing the black-body material. Thus Planck was confident in his assumption that the system was entirely thermal/entropic in nature.

Although Planck introduced his revolutionary Resonance Hypothesis, knitting together concepts of work and electromagnetic energy at the bulk and molecular levels, the incredible events of the quantum revolution may have overtaken him. It appears that he never revisited his Resonance Hypothesis in later writings. After Einstein popularized the Quantum Hypothesis in his famous papers of 1905, the attention of the world was riveted on its breathtaking implications. If Planck did consider a mathematical resonance factor during his many years work on resonant electromagnetic radiation, it remained hidden in his working drafts, and has been one of Einstein's "hidden variables" all these years.

By 1909, Planck had been invited by the President of Columbia University to give a series of lectures on "*the fundamental laws which rule in the physics of today, of the most important hypotheses employed, and of the great ideas which have recently forced themselves into the subject.*" Notably, Planck spent several lectures discussing aspects of his Quantum Hypothesis, but never mentioned his Resonance Hypothesis. He confined his remarks to the purely thermal/entropic aspects of electromagnetic radiation, much as he did in his black-body paper. In his lectures, Planck focused on describing a mathematical foundation for the irreversibility of an increase in entropy (2nd law of thermodynamics), much as Helmholtz had done for conservation of energy (1st law of thermodynamics).

Planck's lectures show that his thoughts and concepts had evolved and changed in regard to his own theories on entropy, irreversibility, and electromagnetic energy on the one hand, and Helmholtz's theories on energy and its conservation on the other. Planck stated in his Columbia lectures, *"To be sure, the view of Helmholtz is not broad enough to include irreversible processes... [T]he method of Helmholtz permits of being carried through consistently...[only] so long as one limits himself to the consideration of reversible processes. ... Reversible processes form only an ideal abstraction...[and] irreversible processes are the only processes occurring in nature."* Thus by

1909, Planck was drawing clear distinctions between Helmholtz's work and his own later work regarding irreversible processes.

Planck never provided a mathematical foundation for his Resonance Hypothesis, which had been based directly on Helmholtz's method. One can easily imagine that Planck's great enthusiasm for the proof of irreversible processes induced him to focus on laying the mathematical foundation for entropy, rather than spending time on Helmholtz-related processes which he considered to be only ideal abstractions. His Resonance Hypothesis receded into the dim obscurity of the history books, never having had the bright spotlight of thought and analysis shone on it.

In the absence of a well articulated mathematical foundation for the Resonance Hypothesis, the development of resonance sciences was fragmented at best. Spectroscopy – the study of resonant energy distribution vs. Boltzmann thermal distribution - developed without the benefit of a mathematical foundation from Planck's Resonance Hypothesis. Resonance concepts were given names which describe what they are "not" (rather than what they are), or used thermal terms as proxies. For example, the resonant distribution of molecules over their energy states was described in the negative as a "non-Boltzmann distribution". The increase in internal energy from resonant energy absorbed by a system was designated "vibrational or apparent *temperature*".

The Boltzmann statistical methods, with their assumption of completely random and disordered motion, were increasingly relied upon. In all the excitement over the new quantum discoveries, the fact that the black-body device deliberately excluded all resonant work energy (and thus described only a subset of the total universe) was forgotten. The probabilities provided by the statistical approach took center stage. Although Erwin Schrödinger attempted to include resonance concepts in the development of quantum mechanics, he was unsuccessful. Schrödinger introduced resonance theories in his early papers about his wave equation, and suggested that the energy states or levels described by quantum mechanics were really the result of different real and physical resonant wave states of atoms, and should be interpreted as such: *"As Heisenberg points out, it is a question of a simple resonance phenomenon with beats, similar to the phenomenon of the so-called sympathetic pendulum."*[18] Much to Schrödinger's chagrin, his wave equations were interpreted as just probabilities and not real physical descriptions. The resonant state was outside the boundaries of Planck's black-body radiation analysis and derivation, and so the theoretical foundation and interpretation based on his black-body work simply did not provide the tools needed to address the issues being raised. Schrödinger's resonance theories were forgotten, just as Planck's Resonance Hypothesis was.

While a complete mathematical foundation is beyond the scope of the current paper, a few important resonance concepts can be gleaned in relation to the Boltzmann mechanics. In the Boltzmann statistical methods, the motion of all elements or molecules in the system is assumed to be *random*, and the distribution of the energy states is described using a Boltzmann weight of "$e^{-E/kT}$". In a resonant system, at least some of the motion is ordered. The presence of the ordered, resonant work energy in the system brings about a change in state, and the total internal energy is greater than the energy of the counterpart thermal system. Thus, in the resonant system the Boltzmann weight no can no longer accurately describe the distribution of energy states in the system. Instead, the resonant energy produces a resonant (non-Boltzmann) distribution of energy states. Using the resonance factor - r_f – the resonant "Boltzmann" weight becomes:

$$e^{-E/rkT}$$

This resonant weighting would be expected to produce a bulge in the energy state distribution curve, rather than a smooth and gradual distribution of energy states. (Figure 5. below) After the system has absorbed a finite amount of resonant energy, the internal energy is increased and at least a portion of the system occupies a higher energy state. As the energy of this higher state is converted to work, the system falls to progressively lower and lower energy states. The resonant bulge would move through the energy distribution curve, the way a meal moves through a snake. Eventually, all of the resonant electromagnetic Helmholtz energy would be converted to work and the system would devolve back to a typical smooth and gradual Boltzmann thermal distribution curve.

The work performed by the resonant energy as the system devolves from a resonant state distribution back to a thermal Boltzmann distribution can shift the equilibrium of the system and produce dramatic changes in its chemical and material dynamics. Equilibria of chemical *thermo*dynamics were described by J. Willard Gibbs in 1902, who formulated chemical free energy ("G") as a variation of the Helmholtz work energy, namely $G = A + pV$ (where "p" is pressure and "V" is volume). The free energy is converted to work, which in turn transforms the reactants into products, decreasing

Cold   Hot   Initial Resonant Energy   Conversion of Energy to Work

Energy

Molecular Population

a. Boltzmann thermal distribution   b. Resonant (Non-Boltzmann) distribution
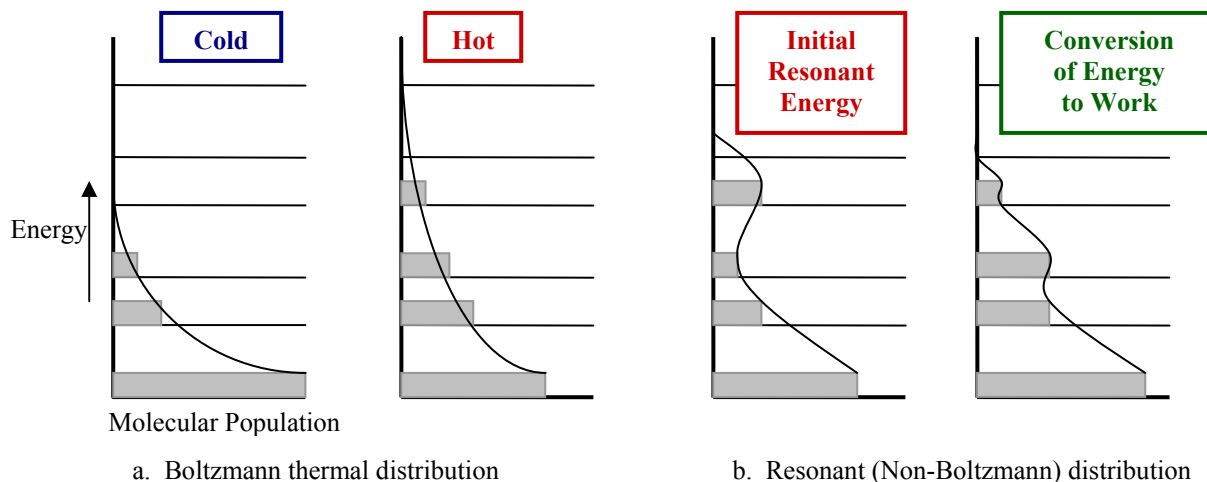
Figure 5. Diagrammatic comparison of Boltzmann energy state distribution to Resonant energy state distribution. The vertical axis shows increasing energy states, and the horizontal axis shows populations of molecules in various energy states.

reactant concentration and increasing product concentration. When the free energy reaches a minimum, the system is in a state of dynamic equilibrium. It is called a "dynamic" equilibrium because reactants are still being changed into products, however products are also being changed back into reactants. These opposite reactions occur at the same rate. Product concentrations no longer change or increase, and so the system is in a state of dynamic equilibrium. The ratio of product concentration to reactant concentration - [products] / [reactants] – is used to describe where the dynamic equilibrium is, on a scale ranging from 100% reactants to 100% products (see Figure 6.a., below).

This ratio of product to reactant concentrations is called the equilibrium constant, "K", for the reaction. Thus, K = [products] / [reactants]. Using the statistical methods of Boltzmann, the equilibrium constant can also be formulated as "K = $e^{-\Delta E/kT}$" (where ΔE is either the Helmholtz or Gibbs chemical free energy). This Boltzmann statistical approach assumes, of course, that all motion in the system is disordered and random. When resonant energy is added to a chemical or material system, at least some of the motions become ordered and are "*completely free to be converted into work*".   The free energy in the system increases and more work can be performed on the reactants in the resonant system, than in its counterpart thermal system. If the concentration of product increases relative to reactant, then the value of the equilibrium constant will be greater as well. In a manner analogous to the resonant energy state weighting discussed above, the resonant equilibrium constant, "K_r" becomes, K_r = $e^{-\Delta E/rkT}$". In other words, the free energy equilibrium curve can be shifted to the right (Fig. 6.b, below).
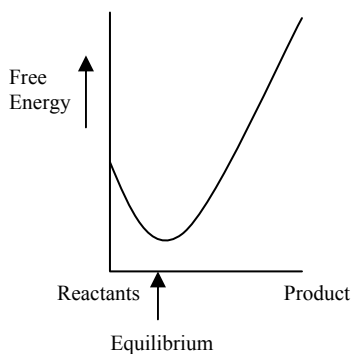

Free Energy

Reactants   Product

Equilibrium

Figure 6.a. Thermal System

Free Energy

Equilibrium shift

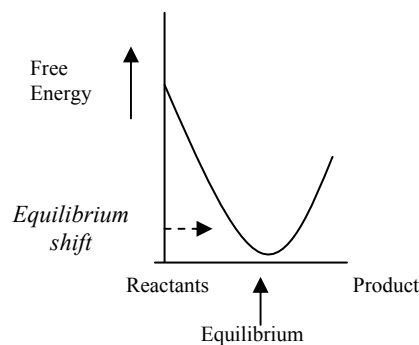Reactants   Product

Equilibrium

Figure 6.b. Resonant System

7. CONCLUSION

When Planck performed his black-body radiation and quantum work, he limited his derivations to the non-resonant thermodynamic state, excluding resonance in his boundary conditions. Although Planck proposed a Resonance Hypothesis, he did not pursue its development. Inclusion of resonance in dynamic considerations, places the Boltzmann constant in better perspective as a *minimal* internal (thermal) energy constant. The product of the resonance factor "r_f" and the Boltzmann constant provides for *total* internal energy. Energy state populations in the resonant system are increased, and dynamic equilibria are shifted. The beginnings of a more complete mathematical foundation have been suggested for the electrodynamics of resonance effects, which may provide a realistic model for many unexplained experimental phenomena related to the frequency-specific effects of electromagnetic energy and fields.

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