The Cosmological Views of Nernst: an Appraisal

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1. From Thermodynamics to Cosmology

Walther Nernst is best known for his contributions to thermodynamics, and in particular for the third law of thermodynamics, for which he received the Nobel Prize for Chemistry in 1920. His work at the time when quantum theory was developing rapidly had cosmological implications which he explored in 1937 in a paper which has been overlooked.

The cosmological work of Nernst has been brought to my attention by A.K.T. Assis and C.R. Keys because of the similarity of Nernst's ideas with my own ideas, some of which were published in earlier issues of this journal (Browne 1994a,b). Helped by translations of Nernst's papers by Peter Huber and Gabriella Moesle (see other essay in this issue), I review now how the separate lines of thought come together.

The character and properties of the æther provide a direct connection between thermodynamics and cosmdogy. How Nernst's work integrated with the ideas prevalent in the years 1906-1916 is made particularly clear by Whittaker (1951) in his two-volume study *A History of the Theories of the Æther and Electricity*. In the preface to the second volume, Whittaker writes:

> *As everyone knows, the æther played a great part in the physics of the nineteenth century; but, in the first decades of the twentieth century, chiefly as a result of failure to observe the earth's motion relative to the æther, and the acceptance of the principle that such attempts must always fail, the word 'æther' fell out of favour, and it became customary to refer to the interplanetary space as 'vacuous'; the vacuum being conceived as mere emptiness, having no properties except that of propagatin.g electromagnetic waves. But with the development of quantum electrodynamics, the vacuum has come to be regarded as the seat of 'zero-point' fluctuations of electric charge and current, and of a 'polarization' corresponding to a dielectric constant different from unity. It seems absurd to retain the name 'vacuum' for an entity so rich in physical properties, and the historical word 'æther' may fittingly be retained.*

2. "Heat Death" of Universe

The second law of thermodynamics asserts: in any process in which a thermally isolated system goes from one macrostate to another, the entropy S tends to increase, specifically as $\Delta S \geq 0$. The third law asserts: the entropy S of a system has the limiting property that S tends to a constant independent of the parameters of any particular system as absolute temperature T tends to zero.

Nernst (1912), in a paper entitled *On Recent Developments in Thermodynamics*, drew attention to the radioactive decay of nuclei as an irreversible process (one of many) which contributes to steadily increasing entropy for the Universe. Potential energy stored in Universal matter appears to be steadily converted into heat without any reverse process to replenish it—that is to say, without creation of matter. He writes:

> *If the conversion of heat back into work or, equivalently, into the kinetic energy of moving masses is only partly (or not at all) possible, and if, conversely, all natural processes take place such that a certain amount of work is transformed into heat, or, one might say, into degraded energy, then all events in the Universe proceed in one direction such that the decay progresses steadily. It follows that all potentials that can still produce work will vanish, and, therefore, all visible motions in the Universe should finally cease.*

This "heat death" for the Universe was unpalatable to Nernst, who goes on to write in the same paper:

> *Nevertheless, there seems to be a possible way out, if we assume some process that counteracts radioactive decay, perhaps imagining that the atoms of all elements of the Universe soon or later entirely dissolve in some primary substance, which we would have to identify with a hypothetical medium of the luminiferous æther. However, in this medium, which behaves much like a gas (as in kinetic theory), all possible configurations can presumably occur, even the most improbable ones, and consequently, an atom of some element (most likely one with high atomic weight) would have to be recreated from time to time.*

3. Zero Point Energy

Nernst (1916) in a paper entitled *An Attempt to Return to the Assumption of Continuous Energy Variations from Quantum Theoretical Considerations* contributed to a problem which lies at the root of quantum theory—the problem of how specific heat (then termed "atomic heat") varies as absolute zero of temperature is approached. The problem is highlighted in most introductory texts to quantum mechanics.

According to statistical mechanics, the average energy of a particle of mass m performing a simple harmonic oscillation with frequency $\omega (= 2\pi\nu)$ is

$$E(p,q) = \frac{p^2}{2m} + \frac{m\omega^2}{2} q^2 \qquad (1)$$

where p is the momentum and q is the displacement from the equilibrium position. The average energy $\bar{E}$ at thermal equilibrium as obtained from

$$\bar{E} = \frac{\int E(p,q) \exp\left[-E(p,q)/kT\right] \mathrm{d}p\mathrm{d}q}{\int \exp\left[-E(p,q)/kT\right] \mathrm{d}p\mathrm{d}q} = \frac{kT}{2} + \frac{kT}{2} = kT \qquad (2)$$

Thus, the oscillator has energy $\varepsilon = kT/2$ per degree of freedom, displacement being a degree of freedom additional to velocity. For N harmonic oscillators in three dimensions we have $E = 3NkT$, and the specific heat at constant volume due to atomic vibrations in a solid is

$$C_\nu = \frac{dE}{dT} = 3Nk = 3R \qquad (3)$$

In the kinetic theory of gases, the degrees of freedom associated with potential energy are absent, so that $C_\nu = 3R/2$.

This law of specific heat, attributed to Dulong and Petit, was recognized by Nernst to be unsatisfactory. Planck, thinking of radiation oscillators in the walls of a cavity containing an equilibrium radiation of all frequencies, had modified the classical result (3) to

$$\bar{E} = \frac{\sum_n nxe^{-nx}}{\sum_n nxe^{-nx}} = kTx\left(e^x - 1\right)^{-1} \qquad (4)$$

where $x = h\nu/kT$. Of course, Planck was concerned to obtain the energy density of radiation in the frequency band $\nu \to \nu + \mathrm{d}\nu$. Thus, he multiplied $\bar{E}$ given by (4) by the number of standing wave modes (two polarizations) in volume V in frequency interval $\nu \to \nu + \mathrm{d}\nu$, obtaining

$$C_\nu = \frac{8\pi\nu^2 \mathrm{d}\nu}{\mathrm{c}^3} \frac{h\nu}{e^x - 1} \qquad (5)$$

Now energy per degree of freedom is $\varepsilon = (kT/2)x/(e^x - 1)$, and the specific heat due to oscillators, radiation or atomic, is

$$C = 3Rx^2 e^x \left(e^x - 1\right)^{-2} \qquad (6)$$

which satisfies Nernst's requirement, $C_\nu \to 0$ as $T \to 0$. Atomic vibrations in a solid are treated similarly to Planck's radiation oscillators, the only difference being that c^{-2} in (5) is replaced by

$$2c_t^{-3} + c_l^{-3} \qquad (8)$$

where c_t and c_l are velocities for transverse and longitudinal waves in an isotropic elastic medium. Debye summed over the modes in the elastic medium setting off the frequency at the point where the number of modes equals the number of atoms in the solid. The result was $C_\nu \propto T^3$.

Planck, in 1911, was still dissatisfied with his new theory for radiation. In what was termed "Planck's second theory", he accommodated continuous absorption of radiation by an atom (as implied by Maxwell's theory) with apparently discontinuous emission in quanta (demanded by his theory) by modifying the mean energy per one-dimensional oscillator from (4) to

$$\varepsilon = \frac{h\nu}{2} + \frac{h\nu}{e^x - 1} = \frac{h\nu}{2} \frac{e^x + 1}{e^x - 1} \qquad (9)$$

Here, zero-point energy of $h\nu/2$ per degree of freedom enters the expression. A consequence of the zero-point energy was that an electron in a stationary atomic state does not spiral into the nucleus if it absorbs zero-point energy at a rate which balances the rate at which it radiates energy. Only if the latter exceeds the former does it radiate. What zero-point radiation really does is to permit the concept of ground state, from which further decays do not occur.

In regard to Planck's zero-point energy, Nernst (1916) describes his attitude as follows:

> *At first it was hard for me to believe in such a zero-point energy, which apparently has nothing in common with heat and concerning whose origin we have no ideas. Furthermore, I was bothered by the consequence that an electron that is oscillating—or better, circulating—around its zero-point energy should not emit radiation, and hence classical electrodynamics should also break down at small dimensions. These difficulties disappear if the original zero-point energy hypothesis is generalized as follows: Even without the existence of radiating matter, i.e., matter heated above absolute zero or somehow stimulated, empty space—or, as we prefer to say, the luminiferous æther—is filled with radiation. The spatial density of energy at a frequency ν is given by the equation*
>
> $$u_o = \frac{8\pi h}{c^3}\nu^3. \qquad (10)$$
>
> *According to well-known principles a linear-oscillating electron, which is appropriately bound by quasi-elastic forces acquires the energy*
>
> $$E_o = h\nu. \qquad (11)$$
>
> *An electron oscillating in this way thus merely puts itself into equilibrium with the zero-point radiation. The laws of electrodynamics are, accordingly, not jeopardized, while the zero-point energy complies with the laws of electrodynamics.*
>
> *A principle which I stated once before, but which had been tacitly accepted by most scientists even earlier, states that an uncharged atom behaves like a charged*

atom or electron with respect to heat motion. Accordingly, every atom, and likewise every conglomerate of atoms, which is capable of oscillation at a frequency ν per second owing to its mechanical conditions, will per degree of freedom take up the kinetic energy

$$E_o = \frac{h\nu}{2} \qquad (12)$$

as already noted, at the absolute zero. [...]
Unlike the usual heat motion, but in accordance with thermodynamics, the zero-point energy is, like every other form of energy at absolute zero, free energy.

The later formal development of quantum mechanics, of course, justified Planck's zero-point radiation in that the eigenstates of the simple harmonic oscillator of frequency ν have energies

$$E_n = \left(n + \tfrac{1}{2}\right)h\nu \qquad (13)$$

where n is an integer. At absolute zero, $n = 0$, so that the oscillator still has energy $h\nu/2$. Transitions $n+1 \rightarrow n$ and $n \rightarrow n+1$ of the harmonic oscillator occur at rates proportional to $n+1$ and n respectively, so that the ratio of emission rate to absorption rate is $(n+1)/n$. The rate of emissions therefore has a term n proportional to the existing intensity of the radiation field at the transition frequency (stimulated emission) and a term independent of this intensity (spontaneous emission) whose origin is related to the $\tfrac{1}{2}$ in (13), and therefore to zero-point radiation.

Consider radiation trapped by perfectly reflecting walls of a cylinder closed at one end by a piston, and let the piston compress the radiation adiabatically, so that the work done by the piston $p\mathrm{d}V$, where p is radiation pressure, equals the change of internal energy $d(uV)$, V being the volume and u the energy density. We write $p = \int p_\nu \mathrm{d}\nu$ and $u = \int u_\nu \mathrm{d}\nu$, where p_ν and u_ν are the contributions within frequency band $\nu \rightarrow \nu + \mathrm{d}\nu$. Let $I_\nu \mathrm{d}\nu$ be the intensity of radiation in frequency band $\nu \rightarrow \nu + \mathrm{d}\nu$, so that flux density incident in solid angle $\mathrm{d}\Omega$ at angle θ on area S of the piston is $I_\nu \mathrm{d}\nu\, \mathrm{d}\Omega \cos\theta\, S$. The energy taken out of the ν-radiation field in frequency band $\mathrm{d}\nu$ and in solid angle $\mathrm{d}\Omega$ in time dt is $I_\nu(\nu)\mathrm{d}\nu\, \mathrm{d}\Omega\cos\theta\, S\mathrm{d}t$. The energy returned after reflection to the same frequency band is $I_\nu(\nu')\mathrm{d}\nu'\, \mathrm{d}\Omega\cos\theta\, S\mathrm{d}t$, where due to Doppler effect

$$\frac{\nu'}{\nu} = 1 - \frac{2v\cos\theta}{c} \qquad (14)$$

Then, equating input minus output integrated over θ to $d(u_\nu V)\mathrm{d}\nu$, we obtain

$$d(u_\nu V) = S dt \int \left[I_\nu(\nu') - I_\nu(\nu)\right]\cos\theta\, \mathrm{d}\Omega \qquad (15)$$

where, using (14),

$$\begin{aligned} I_\nu(\nu') - I_\nu(\nu) &= \frac{dI_\nu}{d\nu}(\nu' - \nu) \\ &= -\frac{dI_\nu}{d\nu}\frac{\cos\theta\; 2v}{c} \end{aligned} \qquad (16)$$

Substituting (16) into (15) with $\mathrm{d}\Omega = 2\pi \sin\theta\, \mathrm{d}\theta$, integration yields

$$d(u_\nu V) = 2\pi S dt \nu \frac{2v}{3c}\frac{dI_\nu}{d\nu} \qquad (17)$$

Finally, we note that $S\nu\, dt = dV$ and $I_\nu = cu_\nu/4\pi$, so that

$$d(u_\nu V) = \frac{\nu}{3}\frac{du_\nu}{d\nu}dV, \qquad (18)$$

which reduces to

$$du = \left(\frac{\nu}{3}\frac{du_\nu}{d\nu} - u_\nu\right)\frac{dV}{V}. \qquad (19)$$

This result, due to Planck, has an important consequence for zero-point energy. In the case of zero-point energy density (10), we note that expression (19) for du_ν vanishes because $u_\nu \propto \nu^3$. Thus, compression of zero-point radiation does not change its energy density or its spectrum, a remarkable property. The result remains valid also for the Planck formula.

Regarding this remarkable property, Nernst (1916) comments:

Any doubts one might raise to zero-point radiation owing to radiation pressure or resistance to moving bodies in the vacuum are overcome by this admittedly strange result. Only by means of mirrors that can reflect very short-wavelength radiation can the zero-point radiation be revealed.

4. Nernst's Stationary Universe

After Hubble discovered the systematic redshifts of the "nebulae", as systems analogous to the Milky Way were then termed, Nernst returned to cosmological studies. In a paper entitled *Further Investigation of the Stationary Universe Hypothesis*, Nernst (1937) states his position as follows:

In the following I would like to develop the notions I put forward in my earlier papers. First, I should like to emphasize that no essential points need to be modified, while my earlier statements, contained in the booklet referred to below, now need to be extended and developed in light of the many new astrophysical measurements, without any fundamental changes to the main ideas. The most important result of my work is the hypothesis, which my earlier studies showed to be plausible, that the Universe is essentially in a stationary state. This hypothesis has proven so useful that it seems unrealistic to ignore it in any serious study of astrophysics.

Nernst continues:

Under these circumstances, it is reasonable to imagine the Universe to be infinitely large and uniform. Moreover, because the nebulae are quite similar in structure—i.e. nebulae in the process of creation or dissolution are not known with certainty—we may conclude that nebulae are very old, our sun (2 to 3 billion years) being comparatively young. Naturally, there must then be a source of energy which can keep such a thermodynamically improbable situation as the formation of many, often very hot stars surrounded by extremely cold regions of space in equilibrium. The so-called "heat-death", therefore, does not exist for astrophysicists, while the creation of new stars out of "chaos" must be regarded as unlikely. Instead, we shall see that all is governed here by a definite set of rules.

Nernst's thinking turns to zero-point radiation, the subject of his previous thermodynamically oriented work. He writes:

In an exposition which is fully congruent with my remarks from 1912, Wiechert notes in his book (shortly before his death he wrote to me that he did not know of my ideas) that there may exist a possible exchange between æther and matter, which is naturally of a statistical nature—exactly as I had supposed. As an example, he mentions radioactive decay, which he imagines as oscillations of the zero-point energy of the luminiferous æther (i.e., a sort of Brownian motion) caused by great quantities of energy.

Again, Nernst (1937) writes:

As early as 1921, I pointed out in Weltgebäude (page 40) that if the Universe was infinitely old, the temperature of intergalactic space should increase continuously due to radiation, whereas we are sure that it has remained extremely low. In order to explain this phenomenon, I then concluded: "The luminiferous æther has the capacity, albeit very small, to absorb heat rays. This absorption can be imagined as the conversion of normal radiation energy into zero-point energy of the luminiferous æther over very long periods of time. In this way we can understand how the temperature can be very low even if the Universe is in a stationary state." This viewpoint has now been widely confirmed by experiments.

While I was searching for an experimental test of the above phenomenon, I came across the well-known redshift of nebulae, and assumed that this was the proof I sought. A loss of energy from light quanta means simply a reduction in its frequency, or a reddening of the light. Since I am referring to my second publication, I will only repeat the points which are necessary to understand the rest of the development. For the gradual decay of light quanta (I perceived a similar phenomenon in mass dissipation—also non-relativistic—even though this process is quite different), we can formulate the simplest equation.

$$-\mathrm{d}(h\nu) = H(h\nu)\,\mathrm{d}t, \qquad (I)$$

i.e., we assume the same kind of decay as observed in monomolecular reactions and radioactive decay. We then obtain

$$\ln\frac{\nu_o}{\nu} = Ht.$$

For a small decrease in frequency we can write

$$\frac{\nu_o - \nu}{\nu} = Ht.$$

The Hubble effect gave him the value $1/H = 1.84\times10^{8}$ yr, which is the time scale on which photons and other forms of energy were supposed to decay. Nernst states:

The constant H (the inverse of a time, which thus has the dimension of frequency), obviously plays the role of a fundamental constant of nature; hH has the value of an energy quantum, yielding a value of 1.2×10^{-64} g. It seems reasonable to suppose that light quanta disappear in these very small quanta, while the same quanta may also apply to gravitational work and kinetic energy.

4. Relevance of Nernst's Cosmology to Recent Ideas

The last paragraph in section 3 is of considerable interest to the author in that precisely this hypothesis was made (Browne 1962) in order to explain the Hubble redshift. Then, the idea was that radiation from a distant galaxy lost these minute quanta of energy (gravitons) slowly to ambient radiation of the medium, which was assumed to be starlight averaged throughout the volume of the Universe.

Earlier, Finlay-Freundlich had aroused considerable interest by the hypothesis of an empirical redshift law which is equivalent to

$$\frac{\Delta\nu}{\nu} = -B\int U\,\mathrm{d}\ell \quad (B = 2.6\times10^{-15}\ \mathrm{cm}^2\ \mathrm{erg}^{-1}) \quad (20)$$

where $\mathrm{d}\ell$ is an element of path in a medium with radiant energy density U. Often, U is blackbody radiation, in which case it can be related to a temperature T by $U = aT^4$, where a = 7.66 × 10^{-15} erg cm^{-3} deg^{-4}, which justifies the original form of the empirical law,

$$\frac{\Delta\nu}{\nu} = -A\int T^4\,\mathrm{d}\ell \quad (A = 2\times10^{-29}\ \mathrm{cm}^{-1}\ \mathrm{deg}^{-4}) \quad (21)$$

where $A = aB$. Finlay-Freundlich had assumed that the effect occurred only in stellar atmospheres. Melvin (1955a,b) corrected the empirical values to $A = 2\times10^{-32}\ \mathrm{cm}^{-1}\ \mathrm{deg}^{-4}$ and $B = 5.7\times10^{-18}\ \mathrm{cm}^2\ \mathrm{erg}^{-1}$ on the grounds that radiation alone (without matter) causes the effect. Finlay-Freundlich noted that the Hubble redshift gave a reasonable value for the temperature of intergalactic space; the value 100 km s^{-1} Mpc^{-1} in (21) implies that $T = 1.5$ K. A measure of the interest in Finlay-Freundlich's proposal can be seen in subsequent comments by McCrea (1954), ter Haar (1954), Born (1954), Burbidge (1954) and Burbidge and Helfer (1955).

About a decade after Finlay-Freundlich's work, Penzias and Wilson (1965) discovered cosmic blackbody radiation with spectrum for $T = 2.735$ K and energy density $U = 4.23 \times 10^{-13}$ erg cm^{-3}. If this value for U is used in (20) with Hubble constant 100 km s^{-1} Mpc^{-1}, then $B = 2.5 \times 10^{-16}$ cm^2 erg^{-1}.

Recently, (Browne 1994a,c) I have argued that zero-point radiation should be used instead of the cosmic blackbody radiation, having a much larger energy density $K\rho_o c^2$. A finite value of $K\rho_o c^2$ was obtained for the zero-point radiation by renormalizing the divergent energy density by gravitational self-potential energy density. The potential for the Newtonian gravitational field inside a sphere of uniform mass density ρ_o and radius R is

$$\phi(r) = 2\pi G\rho_o R^2\left(1 - \frac{r^2}{3R^2}\right) \tag{22}$$

If zero-point energy has divergent energy density U_o of electromagnetic origin, then the gravitational mass equivalent is $4U_o/3Kc^2$, where K is the ratio of inertial to gravitational mass, a constant with dimensions assigned the value unity by choice of the gravitational constant. The factor $\frac{4}{3}$ comes from the mass equivalent of the potential energy density due to radiation pressure. On multiplying by $\phi(0)$, we obtain the gravitational potential energy density of the zero-point radiation, so that the condition that the total energy density should have the finite value $\pm K\rho_o c^2$ is

$$\begin{aligned} \pm K\rho_o c^2 &= U_o - \frac{\left(4U_o/\ 3Kc^2\right)\phi(0)}{2} \\ &= U_o\left(1 - \frac{4\pi G\rho_o R^2}{3Kc^2}\right) \end{aligned} \tag{23}$$

where a factor $\frac{1}{2}$ prevents each element $U\mathrm{d}V$ from being counted twice. If $U_o \to \infty$, we must have

$$4\pi G\rho_o R^2 = 3Kc^2 \tag{24}$$

and hence

$$U^* = K\rho_o c^2 = \frac{3K^2c^4}{4\pi GR^2} \tag{25}$$

On putting $U = U^*$ into (20), we obtain the Hubble redshift $\Delta\nu/\nu = \ell/R$ if

$$B = \frac{4\pi GR^2}{3K^2c^4} = 6.4 \times 10^{-2}\ \text{cm}^2\ \text{erg}^{-1} \tag{26}$$

An explanation of the effect was proposed in terms of scattering of gravitons from the beam being redshifted to radiation of the medium, photons being treated as fields of gravitons of minute energy hH. The theoretical value (26) then implies that the cross-section for graviton scattering is $4\pi a^2/3$, where $a = K^{-1}\left(G\hbar/c^3\right)^{1/2}$ $= 1.6 \times 10^{-33}$ cm (the Planck radius).

Theoretical value (26) is considerably lower than the empirical values. Its acceptance implies that the anomalous redshifts considered by Finlay-Freundlich either have an alternative origin, or perhaps that the theoretical cross section is increased by the gravitational potential field of the star.

What is particularly interesting is that the theoretical cross-section yields very high quasar redshifts of intrinsic origin because of the exceptionally large value of U in quasars. If flux density F is received from a quasar at distance d, then for quasar scale dimension L we have $U \approx Fd^2/L^2c$, and hence

$$\frac{\Delta\nu}{\nu} = -BUL = -\frac{BFd^2}{Lc} \tag{27}$$

Substitution of the values $F \approx 10^{-11}$ erg s^{-1} cm^{-2}, $L \approx 10^{14}$ cm, $B = 6.4 \times 10^{-21}$ cm^2 erg^{-1} and $d \approx 10^{28}$ cm, we infer that $\Delta\nu/\nu \approx 2$. The value for L inferred from the shortest times scales of variability is somewhat conservative, and might well be smaller by an order of magnitude. It follows that most of a quasar's redshift is not a Hubble effect, which implies that the sources are nearer than currently believed, and because d is smaller, U is also smaller.

6. General Speculations

Nernst (1916) envisaged that zero-point energy can play the role of potential energy, writing:

> *If a solid body is compressed at low temperatures, then the ν-values of its atomic or molecular oscillations apparently increase; at least a part of the stored compression must show up as an increase of zero-point energy. The question arises: In the vicinity of absolute zero, is it possible for all the potential energy to consist of zero-point energy? In what follows we shall examine this hypothesis.*
>
> *We first confine ourselves to the vicinity of absolute zero (in the sense of my heat theorem) and look at any system consisting of a number of resonators. For such a system the external work performed for any translation dx would be*
>
> $$\mathrm{d}W = -\frac{\partial \sum \frac{h\nu}{2}}{\partial x}\mathrm{d}x$$
>
> *The zero-point energy content $\sum \frac{h\nu}{2}$ thus plays the role of the potential.*

In his later paper, Nernst (1937) postulates that decay of all types of energy might affect the inverse square law of gravitation Gmm'/r^2 between point masses m and m' separated by distance r. He suggests

$$F = \frac{Gmm'}{r^2}\exp\left(-\frac{rH}{c}\right)$$

His justification for this law is rather interesting; he writes:

If we imagine the Universe to be infinitely large, filled with mass of a limited density, an infinite gravitational force would be exerted on each mass point, though (nearly) evenly from all directions. Following the above considerations, a decay that is similar or even identical to that found for light [Equation (I)] can be assumed for the propagation of gravitation. This removes another source of doubt regarding the hypothesis of an infinite Universe that is on average uniform from all points of view. If we assume that in an infinite Universe masses are distributed not regularly but irregularly (according to statistical fluctuations), every mass in the Universe would be subject to infinitely strong gravitational forces varying in direction, which apparently do not exist.

For the gravity law, instead of

$$K = f\frac{mm'}{r^2}$$

we would have:

$$K = f\frac{mm'}{r^2}\exp\left(-\frac{Hr}{c}\right), \quad (II)$$

and now, if $r = c/H$, the strength of gravitation, like luminosity in the case of light, decreases to 1/e of its usual value. To solve the cosmological problem, people have been trying to correct the law of gravitation for a long time, but the correction was applied to the potential, not, as we had to do by analogy to the propagation of light, to the force.

Nernst goes on to suggest decay of kinetic energy by the same law as he postulates for $h\nu$, by $mv^2/2$. Nernst writes:

A third generalization of the equation for the energy decay of light quanta now suggests itself: kinetic energy too, might vanish in a non-relativistic way over very long periods of time. According to our conception, it actually must, if we view light quanta and mass particles in motion as essentially identical.

The following comments might be made today about the above ideas of Nernst:

1. The infinite gravitational forces F due to statistical fluctuations of mass in a particular direction (defined by some solid angle) in an infinite Universe might be regarded as the origin of the zero-point fluctuations on a particle whose rest mass m tends to zero so that mF remains finite.
2. Whilst light propagation mediates the inverse square of electrostatic force between charges, the same may not be true for the gravitational force between point masses. The former would indeed require a factor $\exp(-rH/c)$, but not necessarily the latter. However, if gravity were a second-order electromagnetic force (van der Waal's force having been suggested), then indeed the factor $\exp(-rH/c)$ might be included for gravitational force.
3. The decay of kinetic energy seems justified only if rest mass m of the particle energy $mv^2/2$ decays, which is a possibility.

7. Astrophysical Evidence for a Stationary Universe

Nernst (1937) postulated a Universe which is in a stationary state because both matter and radiation decay at a rate H equal to the rate at which matter is created in the form of neutrons from a "luminiferous ether." However, Nernst had not the knowledge to properly interpret all astrophysical observations which he claims as support for his hypothesis. He writes (1937):

The energy production of a star per unit mass is clearly divided into two obviously different parts, one which decreases rapidly, and another smaller one that tapers off gradually. In my first publication, I explained this as follows: initially radioactivity predominates, while later atomic splitting is at play. In my second publication, I calculated that if we add known radioactive elements (ionium and uranium II) to the stars in very small percentages we obtain branch I of our curve exactly.

Evidently, the distinction betwen energy release by fission and by fusion of atomic nuclei was unknown to Nernst.

Moreover, Nernst believed that cosmic rays represented radioactive decay of nuclei, which of course is quite wrong. Possibly for this reason he greatly overestimated the importance of neutrons when he claims that new matter is created in the form of neutrons. He writes:

Quite some time ago, before the discovery of neutrons and positrons, I pointed out in the last editions of my book (see above) that the luminiferous æther might consist of massless particles having an electrical charge, which I called "neutrons" at that time. Now, since the isolation of neutrons, we are faced with the hypothesis that neutrons may be created continuously from the luminiferous æther, probably with quite high linear velocities. Naturally, these neutrons would acquire a certain amount of rotational energy when entering the perceptible world, and this would determine their mass. We suppose, as everybody knows, that neutrons can react according to the equation $n = H^+ +$ electron;

Nernst attributed to a nebula a "sphere of action" based on the average distance 2×10^{24} cm between galaxies. The mass lost by a galaxy due to radiation, estimated to be 0.6×10^{33} g per year by Nernst, was balanced by neutron creation in the "sphere of action" of volume 8×10^{72} cm^3. These figures imply that 4 neutrons are created per km^3 every 100 years.

As one of his conclusions, Nernst (1937) writes:

> *Extensive non-relativistic mass decay due to the development of high energies in the interior of stars, as well as non-relativistic decay of light quanta (redshift), both of which I predicted in 1921, both serve as the basis for my theory. Recent astrophysical measurements have practically confirmed the latter phenomenon. On my theory, the redshift is not a Doppler effect.*

The present author, at least, would agree with this conclusion.

Overall, the general idea of matter creation at a rate sufficient to balance matter decay is as much alive today as it was in 1937. However, Nernst does not supply correct detailed mechanisms for either decay or creation, and the evidence he considers to sustain his ideas does not always provide support (*e.g.* cosmic rays).

8. Conclusions

It is remarkable how fashion has dictated the thinking of physicists since the golden era 1900-1930. The ideas of Nernst and some contemporaries of Nernst have been neglected to the point where they are simply not known. Part of the blame must go to the training of physicists, which pays insufficient attention to the historical development of the subject. Moreover, the average student of physics accepts what he is told without questioning its validity, so to a large extent he is indoctrinated. There is much to be gained by retracing the paths followed by early physicists, and in particular by reading the papers of Nernst.

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