The Static Universe of Walther Nernst

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In addition to his work on theromdynamics and chemistry, the great chemo-physicist Walther Nernst investigated cosmology and astrophysics. His bold hypotheses, though long forgotten, may provide new insights into old problems.

Introduction

Walther Nernst (1864-1941) was, without a doubt, one of the most remarkable physicists of the early 20th century. His main accomplishments were in the field of physical chemistry, a discipline he founded together with other well-known scientists, including J.H. van't Hoff, W. Ostwald and S. Arrhenius. His most famous contribution to physics was the so-called third law of thermodynamics, for which he received the Nobel prize for chemistry in 1920. Yet, Nernst's interest was not restricted to pure theoretical considerations; he also produced inventions, such as the Nernst lamp and the Neo-Bechstein piano. Moreover, his profound knowledge of both chemistry and physics enabled him to investigate astrophysical and cosmological processes at a high level of sophistication.

Nernst relates all his main cosmological results—*viz*. the non-existence of a heat death, redshift, background radiation, a solution of the de Chesaux-Olbers paradox, the origin of new atomic matter and gravitation—to the hypothesis of a luminiferous æther. For the heat death problem, the æther serves as a heat sink and the source of new structure. For the redshift, the æther furnishes the energy degradation mechanism. The creation of new matter is a necessity in a Universe which is in a state of equilibrium. For gravitational processes, the æther is the store of energy and the medium that attenuates the gravitational effect over cosmological distances, in a way that is analogous to the redshift of electromagnetic radiation.

In adopting the æther hypothesis, Nernst was not taking a particularly new position. When he began his career, the æther had been the basic postulate for most physicists since Newton. In Nernst's view, however, the æther had a tremendous energy density, its temperature being slightly higher in galaxies than in extragalactic space. This æther energy was quantized in a basic unit, the *Urquant*, which possessed a value *hH*. Even today, the constitution of the æther is just as open a question as it was at the time of Nernst, Maxwell and even Newton.

In recent decades, several workers have developed cosmological theories involving a stationary Universe. In general, the ideas they have proposed have much in common with those put forward by Nernst many decades ago. Yet most of those active in the field are not aware of Nernst's theories. The convergence of independent ideas tells us something of the truth value of these ideas. Thus, it is now essential to restore a correct view of the history of the topic: consistency and the very character of scientific endeavour demand this much.

Nernst's most important paper on cosmological and astrophysical topics is the 1937 work *Further Investigation of the Hypothesis of a Stationary Universe* (*Weitere Prüfung der Annahme eines stationären Zustandes im Weltall*). In this special issue of *Apeiron*, we re-publish this text, which sets out all of Nernst's ideas and views concerning a stationary Universe, in its entirety. The translation from the original German was provided by Peter Huber and Gabriella Moesle. To facilitate comprehension, we provide an introduction and annotations (as endnotes; the footnotes are by Nernst).

The reader will, we expect, appreciate that, even after the classical work of Seeliger and Neumann, Nernst, Zwicky, MacMillan, Hubble and Humason, Einstein and deBroglie in the first decades of this century, and further work by others in recent years (many of whom are familiar to readers of this journal), the most fundamental problems of cosmology still await adequate answers.

Uneasiness with "Heat Death"

Nernst's approach to cosmology arises naturally from his well-known achievements in thermodynamics. In 1905 he stated the original form of the law that is alternately known as the "heat theorem", "Nernst's law" and the "third law of thermodynamics." The law states that the specific heat of a material tends to zero as temperature goes to zero. In the following year, Einstein presented a derivation of this law for solids, applying Planck's quantum theory. By 1910, Nernst and his collaborators had verified the theorem with an extensive series of measurements of specific heats at low temperatures. Then, in 1911, Nernst organized the first Solvay Conference, where Einstein gave the summary talk on the problem. From this foundation, Nernst was able to grapple with the problem of the *Wärmetod*, or heat death of the Universe.

Rudolph Clausius had first presented the theory of a heat death at a conference in Frankfurt in 1867. This event marked the first time the evolutionary conception had been stated in an absolute form, valid for the entire Universe, *i.e.* nature as a whole. By this time, evolutionary processes in nature had become a frequent topic of scientific discussion. Darwin's *Origin of the Species* had been published eight years before; Lamarck's paleontological findings were first made known at the turn of the century; and William Herschel—the first "evolutionary" scientist—had presented a schema for the evolution of cosmic bodies that is valid today (though controversial) in his marvelous garden allegory in 1789.

Prior to the heat death concept, scientific theories of evolution had generally followed philosophical thinking, which saw an unchanging, infinite whole behind the finite local systems. Diverging from this great line of thought, which dates from Hegel back to antiquity, the Aristotelian-Ptolemaic worldview, which dominated until the Enlightenment, held that the cosmos was unchanging. Since the heat death concept was introduced, science has followed a course in which the Aristotelian metaphysical conception of a frozen, unchangeable cosmos has been turned upside down, leading to a concept of total evolution—a view just as metaphysical as its Aristotelian predecessor.

The conception at the base of modern cosmology is truly retrograde. In addition to the thermodynamic "arrow of time", the standard view rests on evolution of everything: expansion of the Universe, its origin at an instant in a finite past, cosmological evolution of galaxies, their systems and the intergalactic medium, as well as the history of the laws of nature through the subsequent separation of forces at an early epoch of the proposed Big Bang. This view of evolution as applying to local systems as a whole, as well as to the totality of nature, may be called hyper-evolutionism.

Nernst's fascination with the *Wärmetod* problem goes back to his student days. In the year 1886 he attended Boltzmann's inaugural lecture at the Viennese Academy, which was devoted to the second law of thermodynamics. In his talk, Boltzmann described the heat death of the Universe as an unavoidable consequence of the second law. From this moment on Nernst sought a resolution to the dilemma.

Nernst could accept neither the heat death nor the idea of expansion, and his stationary Universe excludes other possible forms of global evolution too. In this respect, Nernst—together with Zwicky and MacMillan—can be seen as one of the most notable opponents of the hyper-evolutionism that characterizes science in our century. This places him in a prominent position in the history of the struggle for a scientific world picture.

The claim of a stationary Universe suggests, at least on the surface, a conflict with the second law of thermodynamics, which requires that entropy increase continuously. This is indeed a difficult claim to justify. In the words of Eddington, the second law occupies "the supreme position among the laws of Nature." One may suggest a theory which is in disagreement with Maxwell's equations, but "... if your theory is found to be against the second law of thermodynamics, I can give to you no hope; there is nothing for it but to collapse in deepest humiliation."

Yet the observational evidence necessitates precisely such a theory. In the modern cosmological data, there is nothing whatsoever to support a global increase of entropy. Distant galaxies observed as they were long ago are similar to present, nearby galaxies. Structure in the Cosmos is still extremely rich, in spite of the fact that its age is infinite. The Universe is in equilibrium with respect to all physical processes, the most evident signature of this being the equilibrium blackbody spectrum of the cosmic background radiation. One might even say that the breakdown of the second law of thermodynamics at the cosmological scale is the essence of the law itself: without the reprocessing of matter in an all-pervading æther there could be no structure in the Universe, *i.e.*, no systems in which the law of the increase of entropy could manifest itself.

This loss of potential for work would imply a cessation of all visible motion in a bath of radiation. Nernst then combined Planck's hypothesis of a zero-point energy with the laws of thermodynamics, and was able to envisage a cosmos without the temporal asymmetry of processes assumed by Boltzmann. All energy in the Universe, Nernst argued, which is irreversibly transformed into heat, must be absorbed by the luminiferous æther and stored as zero-point energy. Fluctuations of the æther according to the laws of statistics should create new matter in precisely the amount required for energy decay and matter creation to be in a state of equilibrium. With this new concept, Nernst regarded the demon of heat death as banished forever.

The excerpt on the facing page is from Nernst's first detailed treatment of the heat death problem in 1912. Noteworthy here is Nernst's insistence on the tentative nature of his conclusions with regard to cosmology. This circumspection would be set aside in his later work, once Hubble's discovery of the redshift law had furnished the arguments he needed to close the circle and establish the equilibrium of matter and energy in the Cosmos.

[...] The discovery of the radioactive decay of the elements has acquainted us with energy sources whose power we could never have imagined before. Let us assume—any other view would obviously be arbitrary—that all elements are capable of radioactive decay, and that the majority of the elements split into less complex components too slowly to permit a quantitative appreciation of the decay. We may thus conclude that inside the atoms of all elements are stored energy resources compared to which the heat energy, that is, the kinetic energy of the atoms and the corresponding potential energy, as well as any chemical energy, are infinitely small.

But radioactive processes reveal another striking fact to the thermodynamicist, namely, the phenomenon of irreversibility. While, for instance, we can cause a chemical process of any complexity to reverse its direction by an appropriate variation of experimental conditions, with regard to radioactive processes, on the other hand, we do not have the slightest clue as to whether experimental conditions may exist which cause uranium or another radioactive element to reconstitute itself from its decay products. In fact, we are not even able to alter the speed of radioactive decay by changing external experimental conditions, not even the temperature. Furthermore, the second law of thermodynamics, which applies to reversible processes only, has no relevance to radioactivity, at least as regards a quantitative treatment of these processes.

However, perhaps the phenomena of radioactivity can be related to the consequences of the second law of thermodynamics in other respects. When applied to the Universe, the second law is known to lead to a very fatal result, and all attempts to rescue the Universe from this fate must, at present, be regarded as failures. 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 conclusion is unquestionably correct, and it is absolutely excluded that some combination of diffusion, heat conduction, attraction of masses—whereby a certain amount of visible, active energy is transformed into heat via electrical processes, or, generally, from processes that are subject to the second law—might lead to a some exact result which contradicts the above general requirements of the second law.

The phenomena of radioactive decay are also processes involving a decay of energy, so that they cannot alter the principles underlying the above result, even though the amount of energy stored in the atoms signifies an unexpected increase of potential energy in the Universe. Thus, the so-called heat death of the Universe may be delayed, but it cannot be prevented in the end. Instead, we should say that the theory of radioactive decay of the elements has augmented the above-mentioned decay of energy with a correspondingly steady decay of matter, and thus doubled the likelihood of a *Götterdämmerung* of the Universe.

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 the 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.*

This would only have to occur on rare occasions, owing first to the enormous lifespan of the common chemical elements, and second, to the extremely low density of matter in the Universe (on average, about one grain of mass the size of a pin head every hundred kilometers or so!†). Unfortunately there is almost no chance of experimentally detecting the proposed inversion of radioactive decay and providing an empirical foundation for the above hypothesis.‡ At any rate, it seemed not entirely without interest that there is at present a conception within reach which is not entirely unlikely, whereby the matter and energy content of the Universe could remain in a state of equilibrium. This means that the cessation of all action no longer has to be regarded as an absolute consequence of our present view of nature.

Moreover, we must remain aware of the fact that any experiments performed in the spatially and temporally limited dimensions of our earthbound laboratories necessarily lead to uncertain results when we try to apply them to the orders of magnitude characteristic of cosmological problems. Here we operate with extrapolations, and their reliability is necessarily small. Nevertheless the effort is obviously justified. Following the examples of Kant and Laplace, we cannot abandon the enterprise of constructing an image of the Universe with the aid of well-known empirical facts and more or less probable hypotheses. However, we must constantly recall how uncertain such conclusions might be. Therefore, I would like to propose, in this particular special case, that the above considerations be regarded not as an attempt to introduce a new description of the Universe, but rather as an illustration of our topic, the thermodynamic view.

(Verhandlungen der Gesellschaft deutscher Naturforscher und Ärzte. 84. Versammlung zu Münster i. W. Vom 15. bis 21. September 1912. Erster Teil. Leipzig 1913, p. 100–116)

* In modern astrophysics, heavy elements are fused in nuclear reactions within stars. Evidently, the creation of heavy nuclei in the æther suited Nernst's general picture in accordance with the second law and radioactive decay, which were popular issues of the time.

† With modern values for the parameters, a pin head in every 30,000 km.

‡ The rate of creation of new baryonic matter in a stationary Universe is $C_m = \mathfrak{I}/c^2$, where $\mathfrak{I}$ is luminosity density, $\mathfrak{I}_c = 1.2$ erg s^{-1} Mpc^{-3}, c is the velocity of light. $C_m \approx 3\times10^{-53}$ g s^{-1} cm^{-3}, or one galaxy in a proper volume in 3×10^{14} years, or one proton in a lab of $5\times4\times4$ metres. In spite of the extremely low value of C_m, it may nevertheless be within the range of observation, as C_m coincides with the energy density of cosmic rays with $E > 10^{18}$ eV, usually assumed to make up the extragalactic background.

The Æther, Energy Degradation and the Temperature of the Universe

As noted earlier, in order to avoid the most fatal consequence of the second law of thermodynamics, the universal *Wärmetod*, Nernst defended the concept of an æther, which would allow matter to be reconstituted from fluctuations of the intrinsic zero-point energy, and thus warrant a stationary Universe. In the second decade of the century, a growing number of physicists were prepared to give up the idea of the æther, as the influence of Special Relativity, which made it impossible to use the æther as a standard of motion, spread throughout the physics community. For that reason one can imagine that Nernst was agreeably surprised when he received support from a colleague whose aid he would have never expected: from Einstein himself. In 1920 Einstein published his essay *Æther and the Theory of Relativity* (*Äther und Relativitätstheorie*, Berlin 1920), in which he proposed a revival of the æther with the restriction that it should not contain material properties.

What made Einstein give up his earlier view? When he applied his gravitation theory to the whole Universe, which, like Nernst, he postulated as stationary, he found that it would collapse under its own gravitation. To avoid this unsatisfactory consequence, Einstein had to introduce a cosmological constant l, which produced exactly the necessary amount of pressure to keep the Universe stable. Thus, l could be understood as the energy content of the empty space, *i.e.* of the vacuum. This is precisely the property Nernst had in mind when he wrote, in his popular lecture *The Universe in the Light of Recent Research* (*Das Weltgebäude im Lichte der neueren Forschung*, Berlin 1921):

> *No hypothesis covering the loss of potential energy, which is postulated by the second law of thermodynamics, could succeed without the aid of the energy content of the luminiferous æther (or, if you prefer, 'empty space') (pp. 1ff)*

Apart from Einstein, of course, there were others with a great interest in the æther concept. In the notes to the lecture mentioned above Nernst stated with a touch of pride:

> *That the luminiferous æther contains immense amounts of energy, which is unknowingly organized zero-point energy in the form of oscillation energy, is made likely by my considerations published 1916. Recently E. Wiechert has independently obtained the same result. While I gave a lower limit for this zero-point energy of* 0.36×10^{16} *g/cal. per ccm, Wiechert estimates at least* 7×10^{30} *erg/ccm, which is* 0.9×10^{22} *g/cal. per ccm. (p. 59)*

Here, Nernst is referring to the essay *The Æther in the Physical Picture of the World* (*Der Äther im Weltbild der Physik*, Berlin 1921) by the geophysicist Emil Wiechert, who advocated a material æther concept much like Nernst. While Wiechert criticized Einstein's theory, he welcomed the introduction of l because it seemed to connect the substratum (*Weltuntergrund*) and matter in the sense of Mach's principle.

When it became clear in the early 1920s, that the Theory of Relativity and Quantum Theory were incompatible, Nernst declared himself for the incompleteness of the quantum picture. In his 1922 study *On the Scope of Validity of the Laws of Nature* (*Zum Gültigkeitsbereich der Naturgesetze*), he compared quantum physics with his own field, thermodynamics, pointing out the statistical character of both. He argued that deterministic laws, such as classical mechanics, or even the Theory of Relativity, cannot be more than approximations to an infinitely complex nature. In this sense he wrote,

> *...the work of Galilei and Newton are splendid as a first attempt, but they have not given us the final laws of motion of celestial bodies. And no one wishes to claim that the theory of relativity might perhaps provide the complete set of laws; even the absolute constancy of the velocity of light with which it operates may soon turn out to be an approximation. (p. 491)*

It is remarkable that, although he accepted some results of Einstein's theory, Nernst never lost his doubts concerning constant light velocity, *c*, because it was just this postulate which was in permanent conflict with the æther concept.

During the 1920s, before the observations of Hubble and others of redshifted light from distant galaxies—or, at least, before the observations had been systematized—, the idea of a stationary Universe was quite simple. In his study *Physico-Chemical Considerations in Astrophysics*, published in the English language, Nernst defines the notion of a stationary Universe as follows: ... "that is, the present fixed stars cool continually and new ones are being formed." (p. 135.) In this essay, Nernst goes on to say (p. 141):

> *I may therefore hold fast to the hypothesis uttered by me that, just as the principle of the stationary condition of the cosmos demands that the radiation of the stars be absorbed by the luminiferous æther, so also finally the same thing happens with mass, and that, conversely, strongly active elements are continually being formed from the æther, though naturally not in amounts demonstrable to us, the radio-active disintegration of which maintains correspondingly the high differences of temperature which are observed in the Universe and which at the end form the driving force of all the processes of nature in the direction demanded by the second law of thermo-dynamics. This simple hypothesis would therefore restore to us the stationary condition of the cosmos.*

One problem Nernst's stationary Cosmos had to confront was the radiation problem. Since an unbounded

Universe in which stars and galaxies come into existence and disappear must have existed forever, on the old view there would have to be a continuous increase of radiation. Thus the temperature of the Universe should be extremely high. This argument is known as Olber's paradox. To solve this problem, Nernst, like the American physicist MacMillan, predicted a continuous decay of energy, which he assumed must correspond to absorption by the luminiferous æther, as stated above. Since the amount of absorption should be very small, there appeared to be no likelihood of experimental proof in the near future.

However, the situation changed dramatically with the recognition of the work by Slipher, Humason and Hubble on redshifts. They demonstrated that the characteristic absorption lines of chemical elements in light arriving from distant galaxies was shifted more to the red end of the spectrum the greater the distance to the source. Hubble managed to fit the experimental data to a linear law. He found, for the redshift z

$$z = \frac{n_o - n}{n} = Ht$$

or, multiplied by light velocity c

$$cz = Hct = Hr$$

where $r = ct$ is the distance of a galaxy expressed by the travel time of light and H is a correlation constant, called the Hubble parameter.

In these observations, Nernst found what he was looking for: experimental evidence for his postulated energy degradation! Now he could risk a quantitative approach. Assuming that the energy decay of light behaves just like radioactive decay, in his paper *Further Applications of Physics to Stellar Evolution* (*Einige weitere Anwendungen der Physik auf die Sternentwicklung*, 1935) he postulated that the decay would be given by $\dot{E} = -HE$ where $E = hn$ is the energy of a photon. He recognized that his formula was identical to Hubble's law for short distances. At large distances, however, there should be a divergence between the Doppler interpretation of Hubble's law and Nernst's interpretation, and this might one day serve as a crucial experiment. Nernst, therefore, interpreted the Hubble parameter as quantum decay constant (*Quantenzerfallskonstante*) and postulated a minimal energy quantum hH (*Urquant*). It seems likely that Nernst discovered the energy degradation law independently from F. Zwicky, who had proposed a similar law in 1929.

However, Nernst's interpretation of the cosmological redshift was hardly noticed in 1930. Attention was diverted to non-static solutions of Einstein's gravitational equations due to Friedmann between 1922 and 1924, and after Hubble discovered the redshift law in 1928. In the absence of any readily testable mechanism for energy decay, the Doppler mechanism was preferred.

Steady state cosmology was revived by Bondi and Gold as well as Hoyle in a different form, *i.e.*, with expansion. Matter was supposed to be created at a rate which balanced the rate of loss of matter by expansion. This was followed by the discovery of the 2.7 K blackbody radiation in 1965 by Penzias and Wilson. This radiation was incident isotropically on the telescopes, although we now know of a very small dipole anisotropy due to motion of the Earth relative to the blackbody radiation. Motion relative to the 2.7 K blackbody is measurable, although motion relative to the æther (zero-point radiation) is not. What is interesting here is that Nernst, as early as 1938, had deduced that radiant flux from stars and nebulae in the region between the nebulae should heat absorbing material in this region to 2.7 K, this material then radiating like a blackbody at that temperature. In view of this prediction it is difficult to understand how Big Bang advocates can claim that the 2.7 K blackbody radiation lends any support to this theory, whatever arguments Gamow *et al.* may have presented after the discovery. An essay in this volume by A.K.T. Assis and M.C.D. Neves addresses the history of this problem..

Nernst's contributions to cosmology did not receive the attention they deserved. One reason may certainly be that cosmology soon came to be dominated by General Relativity. The new cosmology, relying on Einstein's equations, necessarily focused on gravitational topics, while Nernst's thermodynamic approach fell out of fashion. Nevertheless, Nernst's views have gained new significance in the current debate over cosmology. Their relevance to that debate is discussed in another essay in this issue of *Apeiron* contributed by P.F. Browne.

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