Further Investigation of the Stationary Universe Hypothesis

by W. Nernst

§1. Introduction. §2. The evolutionary sequence of stars. §3. On "catastrophe theory". §4. Generalizations of Equation (1). §5. On the formation of chemical elements. §6. On the age of meteorites. §7. Reflections on the nova problem. §8. On white dwarfs. §9. Cosmic radiation. §10. Summary.

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§1. *Introduction.* In the following I would like to develop the notions I put forward in my earlier publications.[*] 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.

Recently, Hubble has obtained some extremely important experimental results for a fundamental question in astrophysics, *i.e.*, the so-called spiral nebulæ. Following Hubble, we shall refer to them simply as "nebulæ". These nebulæ are in every respect comparable to our Milky Way system—a fact that was known before—but Hubble has now proved that these nebulæ are distributed extremely regularly in space up to 4 to 500 million light-years away (see below).

Under these circumstances, it is reasonable to imagine the universe to be infinitely large and uniform.[1] Moreover, because the nebulæ are quite similar in structure—*i.e.* nebulæ in the process of creation or dissolution are not known with certainty—we may conclude that nebulæ 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.[2]

As early as 1912,[‡] I suggested the possibility of explaining such a source of energy in physical terms. Wiechert[§] developed a very similar concept in 1921. As no other physically plausible theory is available at present, despite the efforts made by physicists and astrophysicists for many years to find one, we must suppose that no other possible avenues of understanding will be available in the near future.

The theory of a zero-point energy of the luminiferous æther which I postulated in more general terms, and which Wiechert discovered independently a short time afterwards with special reference to gravitation, was summed up in the following concepts in my work[**]. Planck's hypothesis of the zero-point energy referred to oscillating masses; in my generalization, it can be also applied to the medium, *i.e.*, to the luminiferous æther,[3] and this is even necessary if one regards this medium as capable of absorbing energy, a fact which can hardly be denied (*cf.* also discussion of H in §2 below, and notes thereto).[4]

Consequently, we may calculate the energy content of the luminiferous æther at absolute zero analogously to the well-known laws of heat radiation by substituting hn for kT in the appropriate formulas. From the frequency n we obtain a value for the energy density of space

$$m_o = \frac{8ph}{c^3}n^3;$$

while the total quantity of energy would be given by the integral

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[*] *Zeitschrift für Phys*. **97**, 511, 1935 and *Sitzungsber. d. Preuß. Akad. D. Wissenschaften* XXVIII, December 17, 1935, hereinafter referred to as "first" and "second" publications. — Later I will refer to the booklet *Das Weltgebäude im Lichte der neueren Forschung* (1921, Jul. Springer); since it is no longer in print, I will quote the original text. — I reproduce the most important ideas in my second publication for readers of this article.

[†] H.D. Curtis expressed this idea as early as 1933 as follows: "The relative permanency and quasi-eternal duration of these great structures seems a certainty". (*Handb. d. Astrophys*. V. page 887). — Hubble thought along similar lines, calling the nebulae "members of a single family" (*cf.* below.)

[‡] See *Weltgebäude etc.*, *i.e.* the first publication mentioned above.

[§] *Der Äther im Weltbild der Physik*, Berlin 1921. Weidmannsche Buchhandlung, 44 pages. This very interesting booklet, which has nearly been forgotten, can easily be bought in any bookshop.

[**] W. Nernst, *Verhandl. d. Deutsch. Phys. Ges*. **18,** 83. 1916. Pages 89-96 are no longer valid.

$$U_o = \int_0^\infty \frac{8ph}{c^3} n^3 \mathrm{d}n\,,$$

i.e., it would be infinitely great if we were to attribute the luminiferous æther the capacity to absorb oscillations at very high frequencies. If, however, we ascribe a sort of atomic structure to the æther—as is suggested by the facts, and as I have always done[*]—the oscillations must decrease at very high n and finally become extremely weak. If this happens in the vicinity of $n = n'$, we find

$$U_o > \int_0^{n'} \frac{8ph}{c^3} n^3 \mathrm{d}n = \frac{2phn'^4}{c^3}$$

(c = speed of light). In order to find a lower limit for U_o, we may replace n' with the highest known values of n, in other words, values obtained from cosmic radiation. This results in such tremendous values for the energy density (expressed in mass: many tons per cm^3) that the liberation of only a small part of this energy for cosmic events is quite sufficient to maintain the energy balance of the universe, which we can assume from our tables and Hubble's measurements with sufficient certainty.[5]

As many aspects of Hubble's research are quite significant for what follows, I will quote the most important statements (which naturally have only general value because of statistical fluctuations) from his book *The Realm of the Nebulæ* (Oxford, 1936).

— Page 29: "The early impression that the nebulæ were members of a single family appears to be confirmed. The luminosities remain fairly constant through the sequence (mean value, 8.5×10^7 suns,[6] as previously mentioned.... Their masses are uncertain, the estimates ranging from 2×10^9 to 2×10^{11} times the mass of the sun."[†][7] (For now, the lower value seems more probable to me.)

— Page 8: "... the faintest nebulæ that have been photographed ... are at a distance of the order of 500 million light-years."

— Page 31: "The nebulæ are scattered at average intervals of the order of two million light-years or perhaps two hundred times the mean diameters." (When estimating the latter value, allowance must be made for the fact that the stellar density in a nebula decreases outward—just as in our Milky Way system—and therefore these outer parts are not included in our estimation.)

— Page 135: "The light curves, luminosities and spectra [of normal novae] are similar to those of galactic novae. The absolute magnitudes at maximum are symmetrically distributed around the mean value $M = -5.5$, with a dispersion of about 0.5 mag.";[‡] *i.e.*, somewhat more than 10.000 times the magnitude of our sun (which is known to be $-4.^{m}85$). "[One nova] reached a maximum absolute luminosity of about $-14.^{m}5$", *i.e.* 4.000 times the magnitude of a small nova."

— Page 101: "There appears to be an upper limit of stellar luminosity and this limit, about 50,000 times the luminosity of the sun, is closely approximated in most of the great stellar systems." (This value is important for measuring distances.)

Someone not familiar with the subject could easily be misled when reading Hubble's book, as some points appear to deviate from the above rules because of statistical fluctuations. I therefore want to stress the significance of the above summary of Hubble's data, which are of utmost importance for us.

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. Wiechert refutes the apparently inconsequential objection that there cannot be any statistical fluctuations at absolute zero by invoking radioactive decay—an interpretation which remains quite plausible. In any case, we have to be very cautious with hasty criticism if we regard the zero-point energy of the luminiferous æther as given. No one can forbid a scientist to use a working hypothesis logically within its own limits, unless better hypotheses are available. In order to avoid any misunderstanding, I want to emphasize that we can only make very general statements about a possible zero-point energy of the luminiferous æther[**]. For the immediate purposes of this publication, Wiechert's hypothesis and mine are quite sufficient. Finally, I wish to refer to the explanations given on pages 528 and 529 of my first publication.

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[*] *Cf.* editions of my book on theoretical chemistry since 1904, **7**, 13, 1926, pages 464-465.

[†] Since according to the colour index of nebulae, the average brightness of their stars is equal to the brightness of the sun, comparison shows that the nebulae, and naturally also our Milky Way system, consist mainly of dark matter (*cf.* also § 9).

[‡] On the brightness index customarily used in astronomy, see my first publication, page 518.

[§] On this *cf. Weltgebäude etc.*, page 2 *ff.*

[**] Wiechert holds to the known Lorentz contraction; it would seem particularly important to develop this theory further.

Table 1

Spectrum	T	U	M	r	Age (billions of years)	Radiated energy (billions of suns)
K_5	3,570	13,000	32	1.3×10^{-6}	0.002	26
B_0	18,000	10,000	24	0.02	0.003	36
B_1	17,300	4,000	17	0.05	0.0045	42
B_2	16,350	1,600	10	0.08	0.006	45
B_3	15,500	780	6.2	0.11	0.009	47
B_5	13,000	290	4.7	0.13	0.02	50
A_0	9,400	40	2.6	0.19	0.07	52
A_5	7,700	10	1.9	0.32	0.5	56
F_0	6,900	4.3	1.5	0.49	0.8	57
G_0	5,700	1.1	1.1	0.88	2.0	58
K_0	4,800	0.39	0.89	1.2	3.0	58.4
M_1	3,700	0.067	0.60	2.5	6.0	58.6
M_3	3,300	0.034	0.47	2.9	15	58.9

§2. *The evolutionary sequence of stars.*[8] In view of the above, Russell's main sequence must be understood essentially[*] as a continuous evolutionary series, *i.e.*, every star of high initial mass passes through each successive evolutionary state we observe in the sky. There is no doubt about the sequence: stars begin as giants with very low densities (*e.g.*, 10^{-6}), and then gradually condense. The generation of energy U in the interior, as indicated by bolometric energy radiation, decreases continuously due to consumption of active substance. The temperature T then increases, reaching a maximum, and then falls off, so that red giants finally become dense red dwarfs. We know beyond doubt from observations that the stellar mass M declines sharply. I have already described the nature of this decrease in detail in my first publication. Table 2 in that study contains the preliminary results, which are based on data compiled by Dr. Pilowski from observations of double stars. Since then, Dr. Pilowski has subjected the derivation of U and T obtained to date from the observations to critical analysis. In the process, he found that the values used originally required corrections in some respects, without, however, necessitating significant changes to the conclusions I had drawn from those values. Dr. Pilowski's new, considerably improved table is reproduced here.

The temperature is expressed in degrees Celsius, starting from absolute zero; U, M, and r correspond to bolometric energy radiation, mass, and density compared to the sun, which is 1. The density of the sun is, as we know, 1.4. Compared to the values in the first table, the temperature and energy are considerably lower in the initial stage.

The first four rows of numbers and the last row serve only as a provisional orientation because the number of stars measured is insufficient; all the other values should be quite reliable. Further observational material should soon fill the remaining gaps. These shortcomings aside, the above numbers provide us with a fairly detailed picture of the evolution of stars, and they are quite credible from a physical point of view, which naturally indicates that the numbers in the new table represent the physical evolution of a star. By graphical interpolation, we can find the values of temperature, radiated energy and density for any mass.[†] The first column indicates the spectral class of stars, probably their most important property: white Sirius is an A star, the yellow sun is a G. The penultimate column indicates the ages of stars in billions of years, a value deduced from the frequency and from two corresponding absolute time values (see first publication). The last column shows the energy emitted during the time periods indicated in the previous column in billions of suns[‡]. These values can easily be calculated using the values of the third and the sixth columns. When comparing the above table with the corresponding Table 2 in my first publication, the following must be borne in mind: to exclude any arbitrariness, I grouped together similar stars as an average; these average values have not been altered. In the table above, the results have been statistically adjusted so that they show a more regular trend than in my first publication, because at that time the most important question for me was to see whether the direct observations resulted in a *regular* and physically incontestable evolutionary series.

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[*] The provisional table compiled up by Dr. Pilowski and myself (first publication, page 517) is not simply the Russell series; it contains only those stars which obviously show a regular evolution, *i.e.*, excluding the small companions of a double star system; see also §8 and in particular Pilowski, *Astronom. Nachrichten* **261**, 18, 1936.

[†] Naturally only for the members of Russell's main series, but actually for the vast majority of stars.

[‡] See first publication, page 517. The two last columns were calculated by the author.

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.”[9] 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 nebulæ, 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.[10]

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

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

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

If we suppose that the Doppler principle applies, we obtain

$$\frac{\nu_o-\nu}{\nu} = \frac{v}{c}.$$

The measurements show that for a distance of 3.26×10^6 light years,[11] $(\nu_o-\nu)/\nu = 0.00177$. This yields the value[12]

$$H = (1.84\times10^{-9}\ \text{yr})^{-1} = (5.8\times10^{16}\ \text{s})^{-1}$$

In 1.81 billion years the energy of a light quantum decreases therefore by a factor $1/e$ (e = 2.72). For example, for a star at rest at a distance of just 2000 light years, ν_o will thus decrease only by about one millionth due to non-relativistic decay. The redshifts we measured for stars in our system are therefore practically undisturbed Doppler effects, and it is not necessary to correct the various measurements of the radial velocity of stars in our vicinity.

In my first publication, I pointed out that the time had probably not come to develop certain of my ideas about the mass decay of stars; the situation may have changed now. In any case we have found—as shown above—a simple experimentally determined (in astrophysical terms) equation for the non-relativistic dissipation of light quanta. The theory of an “exploding universe” was never very obvious, and we even believe that, with our own interpretation of the redshift of very distant bodies, this theory has now been replaced by a scientifically useful theory.

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.[13] 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 (see § 1).[14]

For all measurements made to date, it makes no difference whether we use $\ln(\nu_o/\nu)$ or $(\nu_o-\nu)/\nu$; however, when Hubble’s research is continued with a more powerful telescope—as is planned—we should be able to settle the very important issue of which law governs the decay of light quanta at large redshift values.

For his distance measurements, Hubble uses the equation

$$t = 1.84\times10^9\,\frac{\nu_o-\nu}{\nu}\ \text{light years},$$

whereas I prefer the formula[‡]

$$t = 1.84\times10^9\,\ln\frac{\nu_o}{\nu}\ \text{light years}.$$

For the greatest distance with which we have worked reliably to date (400 million light years) we obtain from both formulae

$$t = 400\ (\text{or } 368)\times10^6\ \text{light years}$$

which may be a readily observable difference. At higher redshifts this difference should become quite considerable.[15]

Even though I had found it from physical principles by analogy to mass decay, my re-interpretation of the

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[*] According to Regener (*Zeitschrift f. Physik*, **80**, 666, 1933), among other things, the temperature of stellar radiation in our stellar system is about 3.2° (absolute); the temperature must be much lower in internebular space. — The energy of cosmic rays corresponds to a blackbody radiation of about 2.8°. As this value is the same in internebular space, the radiation must be produced almost *exclusively* by cosmic rays.

[†] Perhaps these small quanta also mediate the exchange between the oscillation energy of moving electrons and the zero-point energy of luminiferous ether.

[‡] Both equations show that the observed redshifts for different wavelengths yield the same value for H; if $t = 1/H$, the first equation yields $\nu = \frac{1}{2}$, while mine gives $\nu = 1/e$, but if we apply the Doppler principle, the nebulae would have the velocity of light, which is impossible, whereas my equation should always yield a result that is generally valid.

redshift appeared quite hypothetical at first. It is, therefore, rather remarkable that Hubble[*] himself, *i.e.*, one of the discoverers of the redshift (I suppose he discovered it at the same time as me, though some time later according to his publications), basing himself on astronomical measurements alone, has stated that the Doppler explanation of redshifts is highly unlikely. His arguments must be tested against the astronomical evidence. In any case his measurements have revealed that the decrease of brightness of nebulæ with distance is not as would be required by a Doppler effect: instead, it falls off more slowly, corresponding to my interpretation[†].

A difficult issue, much discussed in years past, is the problem of energy production during the life of stars. The last column of our table gives the quantity of energy radiated by a star that undergoes a normal evolution, which follows simply from the figures for radiated energy and lifetime. These quantities are very high during the first few million years, and then fall off sharply. The curve in Figure 1 below offers some remarkable insights into this process. The energy production of a star per unit mass is divided clearly 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 involved. 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. But at the same time, I pointed out that the assumption of "ultraparticles" was preferable. I will discuss this idea in more detail in §5.

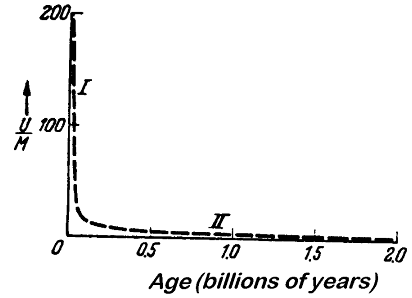

Figure 1

Branch II can easily be explained by atom splitting processes—here we should consider lithium above all—which would have to occur more rapidly with increasing density, so that the decrease due to the consumption of the stellar matter would be largely offset by a higher reaction rate.

I want to stress the fact that the curve shown here does not contain any arbitrary hypotheses. Instead, it results directly from the astrophysical data obtained from observations in our table. In any case, the physical interpretation of energy production inside stars no longer presents any problems.

§3. *On "catastrophe theory"*.[16] For the sake of completeness, I shall now discuss the view, which is occasionally raised, that the Russell main sequence—or more correctly the evolutionary sequence in our table—should be interpreted as indicating that stars of widely different masses in our Milky Way system, and naturally also in the nebulæ, were created "simultaneously": "simultaneously" because the nebulæ behave exactly in the same way as our Milky Way and have the same composition.[‡] The fact that the stars of our universe, including the nebulæ, are very different would have to be explained as follows: stars of a very considerable initial mass would have cooled down and become denser more slowly than stars with a smaller initial mass.[17]

In formal logic, this supposition, in particular the simultaneous creation of nebulæ, cannot be absolutely denied, even though the catastrophic creation of the entire population of stars of differing masses in a single instant is difficult to understand in scientific terms. For me and for all scientists who believe their task is to strive for a theory which is, at least in principle, physically understandable, this hypothesis is entirely precluded. It was above all the theory of the "exploding universe", which is now no longer unacceptable, that made such conceptions possible. For the sake of completeness, however, I would like to demonstrate the futility of this theory with further observations, even if the theory now seems to have lost all support.

If we suppose that the sun is 2 to 3 billion years old,[18] which is hardly doubted any more, then before this time a catastrophic event must have taken place which involved our Milky Way as well as the whole universe. If, however, the nebulæ were created at the same instant as our sun and other stars in the Milky Way, all nebulæ would cool down uniformly. In other words, they must have become redder over time. Yet we see the very distant nebulæ as they were about 500 million years ago, when numerous stars similar to the sun radiated whiter than they do than today. The very distant nebulæ should, therefore, have a different colour index from our Milky Way and the nearer nebulæ.[§] This has never been observed, and even if the effect is not very large, it is sufficient to mention this consequence in order to make "catastrophe theory" appear even more improbable than it already is.[19]

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[*] *Cf. Nature*, 12 December 1936, page 1001.

[†] Moreover, I believe that my interpretation of the redshift as a direct consequence of the hypothesis of stationary universe must be regarded as having a high degree of certainty, quite independent of Hubble's evidence.

[‡] If, as catastrophe theory holds, nebulae were created in different time periods, the light from younger nebulae would appear much whiter and from the older ones, much redder than the average for stars in our Milky Way. According to "evolution theory" all nebulae naturally maintain a constant colour index for a very long time.

[§] However, in very distant nebulae the redshift also causes a rather small change in the colour index.

There is, however, a second consideration that can readily be tested, *viz*. the question how would stars behave if they were created at the same instant but with very different masses. In all nebulæ we can find white and red giants, *i.e*., very bright stars with very large masses which are interpreted as the initial state of a star in evolutionary theory. These stars should therefore, like the sun, be 2 to 3 billion years old according to "catastrophe theory", and if based on our measurements we conservatively set the masses at only 40 and the highest bolometric luminosity at only 50,000, they would radiate an energy of

$$50{,}000 \times 2.5 = 1.25 \times 10^4 \text{ billion suns}^{*},$$

corresponding to a relativistic mass decay of

$$1.25 \times 10^4 \times 0.13 \times 10^{30} = 1.6 \times 10^{34} \text{ g},$$

or approximately 8 solar masses. During its existence, the mass of the star would have decreased from 48 solar masses initially to the present mass of 40 due to heat radiation.

This tremendous supply of energy cannot be explained by our present knowledge of physics. Even if we suppose that in the initial stage stars consist only of neutrons or hydrogen, a maximum mass loss of only 0.9% would be possible, *i.e*., somewhat more than half a solar mass (instead of 8). This calculation is based on very reliable data.[†]

Lastly, overall Hubble's more recent results are hardly compatible with "catastrophe theory." Siedentopf also appears to reject it unconditionally.[‡]

§4. *Generalizations of Equation (I)* (§2). This equation, which is rather peculiar from a purely physical point of view, can be generalized in different ways.

As far as astronomy is concerned, it poses definite limits to the possibility of accessing increasingly remote regions of the universe with telescopes. At a distance of 1.8 billion[20] light years, the radiation energy of a star decreases to nearly one third, in twice this distance to one eighth, *etc*. From much greater distances, such a small fraction of the light reaches us that it cannot be detected.

Hubble has reached distances between 400 and 500 million light years, and here the attenuation of light is noticeable, but still tolerable. Assuming that there is no light dissipation in extragalactic space, and if we suppose, as we did at the start, that the universe is infinitely large and filled uniformly with nebulæ, the firmament would radiate with nearly the luminosity of the sun (average colour index of the nebulæ). If the above equation is valid, this consequence vanishes, and only a very small amount of light remains, because the density of nebulæ in space is much lower.

However, the low luminosity of the firmament has never raised any serious problems, even when Equation (I) was unknown, since it was assumed, *e.g*., that the light would be absorbed by cosmic dust or some similar substance.[21] Our equation, however, provides a simple quantitative explanation, without any further dubious assumptions.

An analogous cosmic problem, the so-called "cosmological paradox," can be solved along similar lines. If we imagine a 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.[22]

For the gravity law, instead of

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

we would have:

$$K = f\,\frac{mm'}{r^2}\,e^{-rH/c}, \qquad \text{(II)}$$

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. It is, however, more important to point out that this is no longer, as in the past, an arbitrary modification of the law of gravitation, but a modification suggested by experimental facts (the redshift, *etc*.).[23] A direct experimental test of Equation (II) seems out of the question.[24]

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. We then obtain a third equation:

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[*] 1 billion suns $= 1.17 \times 10^{50}$ erg $= 0.13 \times 10^{30}$ g.

[†] The age of the sun is often estimated to be higher than I indicated, *i.e*., about 3 to 4 billion years; in this case, the contradiction noted becomes proportionately more acute.

[‡] *Grundlagen der Kosmogonie* (Foundations of Cosmogony) (Göttingen 1928), page 43: "All things considered, an evolution with constant mass would seem rather unlikely." On this view, my hypothesis of "non-relativistic mass loss" could hardy be avoided.

[§] *Cf*. W. Grotrian and A. Kopff, *Erforschung des Weltalls (*Exploring the Universe), article by E.T. Freundlich, page 202. — The following explanation can be given for our equation (II): the repulsive effect of light pressure is weakened by our new time-dependent phenomenon (Equation I), as is Newton's attraction.

$$-\frac{\mathrm{d}\left(\frac{mv^2}{2}\right)}{\mathrm{d}t} = H\left(\frac{mv^2}{2}\right). \qquad \text{(III)}$$

It is, however, doubtful whether we can apply this equation to stellar velocities. In the course of the many millions of years needed to show up the expected effect, gravitational effects could neutralize it completely.[25]

We assume that nebulæ are distributed fairly uniformly in space. Given their tremendous age, any translational motion of their centres of gravity should have ceased by now. Whether we should expect strong gravitational effects caused by nearby nebulæ is not certain. Considering the age of nebulæ, any substantial *continuous* acceleration should have disturbed their uniform distribution.[26]

Recently, measurements of stellar rotation have been made. A discussion of values for different types of stars is provided by Westgate.[*] As expected, the axis of rotation of the various stars is distributed irregularly in the space. In A stars, the later types have a slightly higher rotational velocity; in B and F stars, the velocity is lower and decreases in colder stars. According to Table 1, the time from the red giants to F_0 stars is too short to show up the proposed effect. Contraction and mass loss certainly have a much greater influence. But in the later, very long period of stellar evolution the effect could become evident, as demonstrated in observations.

— For any theory of planet formation, it is important that rotational velocity be higher in the initial stages of the evolution, so that the sun also rotated faster when the planets were forming than today. Moreover, the fundamental importance of the implications of Equation (III) or some qualitatively similar one is that kinetic energy, and thus also the velocity in the luminiferous æther, are absolute quantities, much like mass and luminosity.

Prof. Dr. Unsöld recently sent me the following important observation concerning these questions: “It is actually very strange that the angular momentum of the whole planetary system is on the same order as A stars, according to O. Struve and Ch. Westgate.” Perhaps Equation (III) has some significance for the creation of the planetary system after all.

— In all these issues, the problem of how to characterize the non-relativistic mass decay appearing on our conception remains unresolved. For some time yet we shall probably have to assume, as was done implicitly here, that the momentary kinetic energy disappears in a non-relativistic way simultaneously with the mass. However, these are questions that will require further clarification.

— It would be logical to apply the now entirely plausible Equation (I), according to which light quanta decay non-relativistically, to normal atoms. In other words, *hn* would be replaced by the mass of the atomic nucleus, whose non-relativistic decay is shown quantitatively in our table, if we consider this table an evolutionary series. But experience tells us phenomena of a *totally different nature* must be involved. As I noted in my first publication (page 533), this mass decay is at least approximately proportional to the energy produced in the stars, and thus of a completely different nature from the energy decay according to equations (I) and (III). If we represent the energy radiation indicated in the last column of our new table and the corresponding mass values in a diagram, we obtain a straight line (or approximately straight, given the uncertain values in the last column of our table). Consequently, the new table confirms with greater precision the conclusion I had reached in my previous publication.

— In celestial bodies, such as planets or moons, where no considerable energy is produced in the interior, non-relativistic mass decay can only be quite small, and in meteorites it is completely lacking.

— Equation (III) can certainly also be applied to the heat motion of atoms and molecules. In other words, every body cools down by itself over very long periods of time. The equations cannot be applied to other motions, however, such as the motion of an electron cloud or motions in a nucleus, because these motions are in equilibrium with the zero-point energy.[†]

§5. *On the formation of chemical elements*. 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

$$\mathrm{n} = \mathrm{H}^+ + \text{electron};$$

Based on our hypothesis, we therefore obtain a universe which contains neutrons, protons and negative electrons, and certainly cosmic dust, meteorites, *etc.* Considering the known reaction capacity of neutrons, all chemical elements can be created out of the above elements. Chemistry teaches that the most stable combinations are not formed immediately, and, therefore, highly radioactive elements of high atomic number may be created in several steps. Our table shows that most of these radioactive elements (“ultraparticles”) decay almost completely in a few million years. The above considera-

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[*] Ch. Westgate, *Astroph. Journ*. **37**, 141, 1932; **78**, 46, 1933; **79**. 357, 1934.

[†] It is not possible to prove that the numerical value of H is the same for equations (I) to (III), though we may assume so for the time being. As I have indicated, equation (I) is reasonably certain, whereas equations (II) and, in particular, (III) must be regarded as provisional solutions (but *cf.* also §9)

tions are therefore a further contribution to the general observations (see above) I made in 1913. The chemical composition of the earth's crust and of meteorites (§6), which were created in an earlier stage in the evolution of stars, probably during planet formation, shows us that the creation of most chemical elements was already complete after some hundred million years of stellar evolution.[27]

As to the question, in what form matter continuously returns to the luminiferous æther, we must now assume that this happens in the form of neutrons with low kinetic energy.[28] Therefore, at least some of the neutrons must have very high kinetic energy when entering the universe, if some of them are able to return to the luminiferous æther with low kinetic energy.[*]

Regarding this latter point, we can make a very interesting and precise calculation. We can derive the amount of mass a nebula loses every year from our table. In a stationary universe, this loss must be offset, according to the above considerations, by neutrons and their derivatives supplied by the luminiferous æther, which provide the material for the creation of new stars. Since we know the average distance between nebulæ, we can calculate the average volume space from which nebulæ make up their lost mass. We can therefore calculate the rate at which neutrons are created from the luminiferous æther in a certain volume.

According to our table, the sun loses 0.6 of its mass in 2 billion years. We can assume that a nebula is made up of one billion stars[†] of solar mass (based on our approximate calculation). Because the solar mass is 2×10^{33} g, an average nebula loses each year

$$\frac{0.6\times 2\times 10^{33}\times 10^{9}}{2\times 10^{9}} = 0.6\times 10^{33}\ \text{g}$$

The average distance between two nebulæ is 2 million light years, or 2×10^{24} cm. The "sphere of action" or volume from which the nebula takes neutrons, or their derivatives formed in the universe, is 8×10^{72} cm^3. Thus, each year a quantity of

$$\frac{0.6\times 10^{33}}{8\times 10^{72}} = 0.75\times 10^{-40}\ \text{g of neutrons}$$ [29]

is created per cm^3. Since one neutron weighs 1.7×10^{-24} g., every year 0.4×10^{-16} neutrons per cm^3, or every 100 years 4 neutrons per km^3, are created out of the luminiferous æther. The principle of this calculation is simple and clear. Some of the values used are uncertain, but they certainly do not contain major errors, and therefore the result is provisionally useful. The significance of these calculations is, of course, that if the assumptions they are based on were completely erroneous, they would lead to meaningless results. But this is not the case here or in many other instances.

If a neutron enters a nearly complete nucleus, its surplus above unity (0.009) is converted into energy. If a nebula obtained only neutrons from its surrounding "sphere of action", it would not be able to consume the excessive quantity of energy.[‡] A large part of the excess energy is apparently transformed into cosmic rays (§9). Moreover, a lot of "dead matter" is certainly required to form new stars, matter consisting of cold stars, meteorites, cosmic dust, all of which we must assume to exist for an indefinite time. Finally, the total energy of neutrons available in a star does not enter into the process, owing to the large quantity of hydrogen it contains.

Recently, a number of observations have proved the existence of neutron rays in cosmic rays, which obviously provides considerable support for my hypothesis.[§] On the other hand, we cannot develop a very detailed theory of star formation, as we have not yet been able to observe stars in their initial stages of evolution. For that matter, little can be said about processes in the interior of stars with certainty, though scientists are quick to put forward theories. Any such theory would certainly have to yield approximate calculations for the evolutionary series given in our table, while energy production should be clarified in its essentials. We would make further progress in this field, if we could estimate heat conduction inside stars; though at present this is certainly not possible.

§6. *On the age of meteorites.*[**] The well-known studies by Paneth on the age of iron meteorites (using the helium method) yielded values of between 0.1 and 3 billion years. The same method yields an age of 1.6 billion years

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[*] Thus, the existence of very hard particles in cosmic rays becomes understandable, a fact which contradicted the hypothesis that only highly radioactive elements could emit such particles.

[†] This number is known only approximately; see also H. Siedentopf. *l.c.* page 47.

[‡] According to our table (last column) a star shines for 59 billion years; this means $59\times 0.13\times 10^{30} = 7.7\times 10^{30}$ g or 0.0040 solar masses. If a star were composed of neutrons (or hydrogen), with an initial mass of 40 it would have an available energy of at least 0.36 solar masses, or about 100 times too much. This calculation, which is physically quite certain, is obviously important (see also §9).

[§] In a mineshaft, Clay, Hooft, Dey, and Wiersma recorded "bursts" (*Physica* IV, February 1937) to depths of 328 meters; the authors are of the opinion that these "bursts" are probably due to very hard neutron radiation. — E. Fünfer (*Naturwissensch*., 9 April 1937), using special counting instruments, succeeded in proving the existence of slow neutrons in the atmosphere, and he states that they may be part of the cosmic radiation, and that the atmosphere may have slowed them down considerably. The author refers here to a publication of L.H. Rumbough and G.L. Locher (*Phys. Rev*. **49**, 855, 1936), who proved the existence of fast neutrons in the stratosphere. — We can complete these observations, if we add to Fünfer's hypothesis the possibility that few extremely fast neutrons not only reach the earth, but they can even pass through a deep layer of matter. — Lastly, E. Regener's colleague, Mr. E. Schopper, has shown that there is considerable neutron radiation the upper atmosphere air, but little at ground level (personal communication).

[**] *Cf.* also F. Heide, *Kleine Meteoritenkunde* (Berlin, Jul. Springer, 1934), C. Hoffmeister, *Die Meteore*, (Leipzig, Akad. Verlagsges., 1937). — Also, J. Rosenhagen, in *Die Sterne*, 1936, pp. 185, 258., and especially also H. V. Kluber, *Vorkommen der Chem. Elemente im Kosmos*, (Leipzig, A. Barth, 1931).

for the earth's crust (naturally we are only interested in the maximum ages!). (Prof. Paneth has kindly informed me that, owing to thorium content, his figures should be reduced, though this changes nothing essential in our approach.)

According to Rosenhagen (*l.c.*, p. 192) and Hoffmeister (*l.c.*, p. 65), the velocity of meteorites almost certainly remains well above the critical value of 42 km s^{-1} at all times, so most of them could not have originated in our solar system.[*] Thus, according to present knowledge, we can only suppose that they originated in powerful eruptions on stars (as in planet formation, *etc.*).[†] If we assume an original velocity of 100 km s^{-1}, the youngest meteorites would have covered a distance of $0.1\times10^9(100\times10^5)/(3\times10^4) = 3\times10^4$ light years in just 100 million light years before reaching us. There are enough stars at this distance to regard such a process as possible.

For the longest calculated times of 3×10^9 years, this would imply stars at 30 times that distance, or around 1 million light years.

Both calculations, however, assume that meteorites come almost directly toward us from the stars where they were born. In the former case, this would *perhaps* be plausible, but certainly not in the latter. It is hardly possible to assume that meteorites reach us from nebulæ, if such is not entirely out of the question.

Accordingly, meteorites must travel a spiral or zigzag path before they eventually land on the earth. The longest period of 3 billion years should represent an upper limit, which is seldom exceeded, since within this time almost all meteorites must have been captured by other stars. Paneth's curious discovery that meteorites are all older than 100 but younger than 3000 million years is thus easily explained, though an extension of our statistics on stars would enable a more precise theoretical determination of the upper limit value. Thus, our considerations lead to the frequency curve shown in Figure 2, which corresponds to Paneth's measurements.[‡]

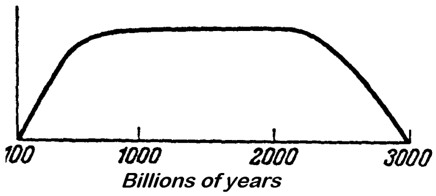

Figure 2

In conclusion, if we assume iron meteorites are catapulted out by explosions in the youthful stages of stars with very high velocities, considerably more than 100 km s^{-1}, then obviously neither very young nor very old meteorites can reach the earth, as the measurements show. The maximum age appears to lie at about 3.0 million, and the maximum frequency at about 2.0 million years. Only meteorites of about the latter age can originate from our own solar system.

When the meteorites were expelled—in the form of glowing masses of gas, as is widely assumed—the star must have had essentially the same chemical composition that we see in meteorites, and which we can safely assume for the earth. Even the proportions of iron, nickel, chlorine and silicon isotopes are the same as on earth.[§]

§7. *Reflections on the nova problem.* From the work by Hubble and his collaborators, who have noted many novae in nebulæ, it is certain that "Two groups of novae [are] obviously indicated, one of which [is] probably several thousand times brighter than the other" (Hubble, *l.c.*, p. 87).The first group is much rarer, perhaps a hundred times more so, than the second group. In the first group, the only well-known example is Nova 1885 in the Andromeda Nebula, which reached –14.5 magnitude at maximum luminosity. Several examples from the second group have been studied in our Milky Way and other nebula. According to Hubble (see above), their maximum luminosity varies little from a mean value of –5.5. Since it is possible to obtain a reasonably sure estimate of distance from the luminosity of a nebula, when a nova is observed in a nebula there is hardly any doubt about which of the two types it falls into, such that the brightness of a nova can be used to determine the distance to a nebula.

More recently, Grotrian[**] has managed to draw very valuable conclusions from a thorough study of the small Hercules Nova of 1934, and these should apply to practically all small novae. In the red dwarf stage—according to our table from 0.5 to 0.8 solar masses and a bolometric luminosity of about 0.3 to 0.5 compared to the sun—an already fairly dense star contracts, apparently because its

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[*] The objection that the fact that meteors are so similar to the earth's crust in chemical composition indicates an origin inside the solar system has been rebutted by Hoffmeister (*l.c.* p. 65). Our theory of the universe actually forbids this. Just as the galaxies are of strikingly similar makeup, so too other heavenly bodies in similar stages of development show the same chemical composition.

[†] It has been certain for some time now that meteorites must have formed at very high temperatures. See for example F. Heide, *l.c.* p. 79. H. V. Kluber characterized them as "platonic mineral fragments" (*Chem. Elemente im Kosmos*, Leipzig, O. Barth, 1931).

[‡] Paneth measured the ages of 25 iron meteorites. They start at 100 and end at 3000 million years. The frequency curve shows a sharp cutoff, as in Figure 2. Compare also F. Heide, *l.c.*, pp. 97 ff.; F. Paneth, D. Uny and W. Koesk, *Nature* 1930, p. 490.

[§] *Cf.* J. Rosenhagen, *l.c.*, p. 190. The chemical composition of the earth's crust, as in the case of the meteorites, where no large amount of energy is being developed, confirms the conclusion given in §4 that non-relativistic mass loss is tied up with high energy production. Any significant mass loss in 3 billion years would have been disclosed in the crystal structure of meteorites.

[**] *Die Sterne*, 1935, pp. 193 and 257.

active mass is practically used up and so the inner light pressure has become small. Very hot masses then break loose from the surface (Milne), and its brightness increases by a factor of 300,000, perhaps also due to the tremendous increase in the star's volume. Then, after a few days, there is a rapid collapse accompanied by notable fluctuations as the star reaches a high density and temperature as a result of its contraction: it becomes a white dwarf. These nova catastrophes occur so often that the same star can presumably go through this stage several times, or even quite often.[*]

Unfortunately, we have too few observations of large novae to be able to be sure about as many details of the process as in the case of small novae. What is characteristic is that the phenomenon is not frequent. This would be understandable if double star formation were involved. This apparently occurs in an early stage of stellar evolution, *i.e.* in stars that are rich in active material and therefore have a very high luminosity. If we consider that stars in this state are much heavier than small novae, that their density is much lower and their radiating surface correspondingly much larger, this gives a quantitative explanation why large novae are much brighter than small ones, even though their exterior temperature at maximum brightness does not need to be much higher than the temperature of small novae. Hence, in these cases the bolometric correction must not make a large contribution, as was once assumed. Furthermore, the Stefan-Boltzmann T^4 radiation law stipulates that the external temperatures of a star can under no circumstances reach catastrophic values, since even assuming extremely high conductivity, a body at high temperature radiating into space is almost immediately (in a few minutes) covered with a cooler layer. This is easy to calculate; failure to consider this has led to some quite fantastic notions about "supernovae". Consequently, the mass loss of a star through radiation (according to Einstein's formula) is at all events small in the nova stage.

The rarity of large novae in comparison to small ones is easily explained using the following (naturally still provisional) hypothesis:

1. A nova stage can only happen once in the lifetime of a star in a double star system, whereas, as noted above, red dwarf stages apparently happen often in the life of a star. Clearly, only in cases where a star splits into two or more *large* fragments is the nova stage very impressive.
2. Double star systems naturally do not occur in all cases, whereas there is no doubt that red dwarf contraction apparently occurs often in all stars of this type.
3. In the literature we often read that double stars are formed by a merger of two stars, so that not necessarily all double stars need have passed through the stage of a large nova. Obviously this phenomenon occurs rarely, if at all.

§8. *On white dwarfs*. On page 532 of my first publication I made a few observations, noting that white dwarfs were apparently to be ranked at the end of the evolutionary sequence in our table, and I explained this position, which I had stated on many occasions. Grotrian (*l.c.*) seems to have confirmed it in connection with Milne's work.[†] Using the double star ζ-Aurigae as an example, we can suppose that contraction occurs as a result of the complete exhaustion of active mass in the star, such that the light pressure, which counteracts contraction, decreases correspondingly. The main star has a very low density of some 10^{-6}, while the companion is about 0.5 (it is apparently not known exactly). However, it is striking that the companion star is 1,000,000 times denser than the main star, but this follows from the rule I established in 1921 (*l.c.*, p. 61) whereby the companion star in a double star system contains, almost without exception, far less active mass than the main star. This can also be demonstrated by comparing the mass of the planets to that of the sun.[‡] Apparently the heavy atoms, such as uranium, *etc.*, which generate internal stellar energy, tend to remain inside the main star after the breakup.

The data for smaller companions are as follows:

M	*T*	*U*	*r*	
12.4	15,000	880	0.20	Guthnick, Schneller and Hachenberg, *Abhandl. D. Preuss. Akad. d. Wissensch.* (1935)
12.4	22,000	800	0.91	Hopmann, *Sachs, Akad. D. Wissensch.*,. June 19, 1935
12.4	16,700	2600	0.07	Interpolated from table for *M* = 12.4

The last row contains calculated values (or at least approximate ones for normal evolution) that a small companion should have. The temperature is normal, *i.e.* not below the value corresponding to normal evolution, because rapid contraction produces considerable gravitational energy[§] in the star. The density, which is the most important characteristic for stellar evolution, as mentioned above, falls off sharply, and it seems highly probable that companions go through the white dwarf stage several times after long intervals. If we make the necessary assumption that gravitational energy balances most of the radiation—this appears quite certain, as the U val-

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[*] H. Siedentopf, *l.c.*, p. 47. I made a similar calculation in my 1922 talk on "New Stars" (Rector's address). However, it is not easy to understand that the small novae all behave so similarly, as it is always assumed. The remarks in my above-mentioned talk are valid only for the large novae. The difference between the apparently widely different processes in large and small novae was not known to me then.

[†] Compare especially W. Grotrian, *ZS f. Astrophys.* **13**, 215, 1937.

[‡] Compare *Weltgebäude*, p. 42.

[§] Compare *ZS. F. Phys.* **97**, p. 531, 1935.

ues are much higher than in normal radiation—we obtain an age estimate (details in the above cited work) which fits well into our table and in turn confirms the basic uranium time measurement. Companions must therefore be approximately 2 million years old.

Now we come up against an unexpected result. We compare ζ-Aurigae with a double star (Sirius), where the companion ($M = 1.0$, $r = 10^5$, T about 8800° and U about 0.004) is a white dwarf, whose age, which our table shows about the same as Sirius, is 70 million years. It is obviously plausible for the ζ-Aurigae companion to reach a density of 0.5 in just 2 million years, and the very high density of a white dwarf in another 70 million years. In fact, it must have reached this density much earlier, since the Sirius companion would have become a white dwarf long before.

The question then arises: Have the Sirius companion and other similar cases passed through the nova stage? If so (assuming it was normal), then the companion must have far outshone the main star for at least a few weeks, since at its maximum the small nova far exceeded the main star in brightness (*cf.* above), which we can presume was a B star. I have no knowledge of anyone observing a star that suddenly becomes brighter for a few weeks.[*] How often this happens is difficult to estimate. Since the internal heat generated in such companions must be far below normal, it is questionable whether it passes through a definite nova stage on its way to becoming a dwarf. — I leave further discussion of this interesting problem to the specialists. From the foregoing, however, it appears certain that two categories of dwarfs must be distinguished, *i.e.* solitary ones and companions, since their evolution is apparently quite different. The Sirius companion is only 70 million years old, while the normal appearance of a small nova and development into a white star occurs at some 3 billion years (*cf.* the table). This too, seems to confirm the hypothesis that the fainter companion in a double star system is far ahead of the main star in its evolution.[†]

§9. *Cosmic radiation.* We must, as Regener has done,[‡] suppose that this radiation originates from the whole universe, in accordance with my 1912 hypothesis, made before it was discovered and in conformity with my approach to astrophysics. Earlier, we made the special hypothesis that non-relativistic neutrons are created primarily in the cosmos (*cf.* especially §5); some of these neutrons have very high kinetic energy and they supply that (small) percentage of radiation which is extremely hard, either directly or via neutron derivatives, which may also contain high energies. If neutrons combine with hydrogen or with bigger units (elements with a high atomic number in the cosmic dust, *etc.*), radioactive nuclei are formed; these nuclei can emit radiation (above all corpuscular radiation) at an energy corresponding to the main component of cosmic radiation. We never detect most of these radioactive elements because they are so short-lived (half-life of only a few million years), but some of them may be present in young stars, as the U-values in our table indicate.[§]

Concerning the question whether cosmic radiation might be emitted for some time in the nova stage, which I discussed in 1922, we must obviously reply now that this seems probable for large novae, but for small novae we can expect only small effects—if any at all (§7).

In the above-mentioned important publication by Regener, we find the claim that a body that absorbs cosmic radiation in the universe should heat up to a maximum of 2.8° (absolute). The resulting energy density of the radiation

$$\frac{4\sigma T^4}{c} = \frac{4\times 5.7\times 10^{-5}(2.8)^4}{3\times 10^{10}} = 4.67\times 10^{-13}\ \text{erg cm}^{-3}$$

yields the energy content of the "sphere of action" of each nebula (8×10^{72} cm^3 as shown above):

$$\begin{aligned} 4.67\times10^{-13}\times 8\times10^{72} &= 3.7\times10^{60}\ \text{erg} \\ &= 4.0\times10^{39}\ \text{g} = 2\times10^{6}\ \text{solar masses.} \end{aligned}$$

This value is surprisingly high if we compare it to the average mass of a nebula (§1) which is only about 500 times greater.

But we must consider that the 2.0×10^6 solar masses just obtained represents available energy (in thermodynamics, "free energy"). As I have mentioned several times, even if a nebula consisted exclusively of neutrons and hydrogen, less than $\frac{1}{100}$ of it would be available energy, and we would obtain the curious result that the empty space surrounding every nebula would contain as much available energy as the nebula itself.[30]

We can verify these results in another way. Above we calculated that a nebula loses 0.6×10^{33} g every year, and presumably this quantity would be compensated continuously in the form of neutrons supplied by the nebula's "sphere of action" with available energy of 0.6×10^{31} g. We noted earlier that a nebula consumed only $\frac{1}{100}$ of this to generate heat radiation. However, according to our equation (see above) cosmic rays representing 4.0×10^{39} g lose

$$-\frac{d(h\nu)}{dt} = \frac{h\nu}{1.84\times10^9} \qquad \text{(I) (or III!)}$$

every year

$$\frac{4.0\times10^{39}}{1.84\times10^9} = 0.22\times10^{31}\ \text{g},$$

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[*] The companion is presumably a very small star, by analogy with the prenovae of small novae. In most cases these are invisible beside a very bright main star, except, naturally, when it temporarily reaches the brightness of a nova.

[†] *Cf.* H. Siedentopf, *Kosmogonie*, Göttingen, 1928, p. 35.

[‡] *Zeitschrift für Physik* **80**, 668, 1933

[§] *Cf.* also second publication, page 637.

and this quantity too, must certainly be supplied by the stationary universe principle. Now, this quantity corresponds approximately, within present limits of precision for such estimations, to the of 0.6×10^{31} g of available energy in the form of neutrons.

We can formulate the above calculation in another way: if we divide the energy of cosmic rays by the annual loss of active mass (0.009 of the mass which is really dissipated), we obtain the reciprocal Hubble constant, *i.e.*,

$$\frac{4.0\times10^{39}}{0.6\times10^{33}\times0.009}=0.74\times10^{9}\ (\text{instead of } 1.84\times10^{9})\ \text{yr.}$$

which is in good agreement, despite uncertainties in the data. The value of the "redshift" has thus been related to observational results, and no such correlation could have been suspected without our theory.

A further application may be considered. The individual parts of the cosmic radiation should exhibit a redshift according to the above calculation. In other words, they are subject to an energy loss over very long periods, which is proportional to the time required for the radiation to travel a certain distance. This means, however, that even if the cosmic radiation had *preferred* energy maximum—as we assume—an observer on the earth could hardly notice anything. It is just as if we wanted to separate the light from numerous nearby and distant nebulæ with a spectroscope. The strong redshifts, which depend on the distance, would appear as a practically continuous spectral band.

In this final section we were drawn to a fundamental change in our understanding of the energy balance in the universe, though, this change in no way contradicts my earlier hypotheses. According to our basic principle, by far the largest part of the available energy in the universe, which, like the mass, must remain constant, serves to keep the cosmic radiation constant, which would otherwise vanish via a phenomenon analogous to the "redshift". This is where the most massive (quantitative) exchange between the zero-point energy of the luminiferous æther and the universe takes place. Compared to this energy, the energy radiated by a nebula, which alone has been studied by astrophysics—and which naturally participates in the same cycle—is very small (0.13×10^{29} against 0.22×10^{31} g per year).*

In summary, we can conceive of universal processes as follows. According to the stationary universe principle, mass, energy, and entropy individually remain constant (though all observe the laws of thermodynamics, which applied hitherto only to processes not involving zero-point energy). In the interior of stars, matter vanishes non-relativistically as an effect of conditions prevailing there, while radiation energy decays according to our equations (I) and (III) (§2). Mass is continuously replaced by neutrons throughout the universe; most of this available mass (0.009) also serves keep the energy of cosmic radiation constant, while only a very small part supplies energy for stellar radiation. Both radiations decay according to the "redshift principle" at rates that can be calculated.

The process of non-relativistic mass decay is still obscure, but we may assume that neutrons with low kinetic energy and atomic weight of 1,000 are constantly absorbed by the luminiferous æther once they are released from atomic nuclei due to radiation in stellar interiors.

Direct, experimental proof of non-relativistic mass decay in the laboratory is not to be excluded.

It seems premature to speculate on details of element formation in stellar interiors, or even on star formation.†

The statements about cosmic radiation made in the course of this study do not give us any specific information, but they apparently constitute the only available working hypothesis in this field at the present time. Once again, the fundamental importance of cosmic radiation for physics and astrophysics is beyond doubt.

§10. *Summary.*

1. Our main purpose was to confirm the hypothesis that the universe is in a stationary state. Once again, we have shown that many long-reaching conclusions result from this working hypothesis.
2. As early as 1912, this hypothesis led me to the conclusion that space had to be full of radioactive radiation. The discovery of cosmic rays provided a clear confirmation; now that I have developed this viewpoint further, many details of cosmic radiation are better understood.
3. Based on my 1903 assumptions about the luminiferous æther, a very special theory of cosmic radiation has now been formulated, whereby its supposed main components are supposed to be very high energy neutrons.
4. At the same time, the existence of fast and, naturally also, of very slow neutrons in the cosmic radiation has been confirmed by different sources, in full agreement with the theory.
5. 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 phenome-

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* It is noteworthy noted that the forms of cosmic energy we are able to measure, stellar radiation and cosmic radiation, are practically "free energy" in the meaning of the second law of thermodynamics.

† We have never observed stars in their early stages of formation; *cf.* however W. Grotrian, *Erforschung des Weltalls*, page 237 (1934, Jul. Springer), according to which it is possible that a planetary nebula with a very hot white dwarf star at the centre represents the initial state in the formation of new stars. — Owing to their peculiar structure, star clusters are not taken into consideration in these observations as they represent a special type of formation.

non. On my theory, the redshift is not a Doppler effect.

6. This supposition has been confirmed in a very different way, independent of my work, by Hubble's astronomical measurements. At the same time, these measurements have excluded the theory of an "exploding universe," which never had any place in my conception.
7. My equation for the redshifts leads to generalizations which are presently based mainly on dimensional considerations, and which are quite remarkable from a physical point of view.
8. With reference to Hubble's measurements, a further basis for the present work was the idea that the universe is infinite and homogeneously filled with nebulæ very much like our Milky Way. These nebulæ may be assumed to be infinitely old.[31] All this can be explained with our hypothesis, in many cases with quantitative results.
9. The homogeneous distribution of nebulæ in space and their similar appearance have been explained and calculated.
10. The age and the formation of meteorites, especially iron meteorites, large and small novae, and the possibility of two, somewhat different types of white dwarfs are interpreted on the basis of my conception, with extensive references to Grotrian's latest studies, though on occasion some special hypotheses which cannot be proved with certainty for the time being must be introduced.
11. Cosmic radiation, which is so important for astrophysics, can now be seen in a new light, since in the stationary universe hypothesis its energy supply is much greater than the energy from stellar radiation.
12. The astrophysical research presented in my publications is an attempt to establish a concept of space that is free from contradiction and physically simple, and provides answers to all more important questions in many cases with quantitative results. My findings should be immune to physical objections, *i.e.* objections based on experimental evidence, since they do not conflict with laboratory experiment. Time will tell whether astronomical research can raise any serious objections.

My colleague, Dr. W. Orthman (private lecturer) once again helped me extensively with the present report. I am also grateful to my astronomy colleagues Mr. Guthnick and Mr. Kopff from Berlin for providing a great deal of astronomical information. I also received many suggestions, above all in the field of cosmic radiation, through correspondence with Prof. E. Regener of Stuttgart.

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1. Nernst draws his conclusion, which is still valid, from Hubble's results on the number counts of galaxies. Hubble himself (1934) made the historically momentous inference from these results, that the observable region is "a fair sample of the Universe as a whole."
2. When Nernst stated his heat theorem in 1906, also referred to as third law of thermodynamics, he was aware of its incompatibility with classical thermodynamics, as the following consideration implies: The equation of an ideal gas is given by
$$pv = RT$$
(p pressure, v volume, R gas constant, T absolute temperature), and the maximum work W which is necessary to expand a gas from the volume v_1 to v_2 is described by
$$W = RT \ln \frac{v_2}{v_1}$$
Differentiation of this classical result ($\Delta T \to 0$) yields
$$\lim \frac{\mathrm{d}W}{\mathrm{d}T} = R \ln \frac{v_2}{v_1} \quad (\text{for } T = 0),$$
whereas Nernst stated in his theorem
$$\lim \frac{\mathrm{d}W}{\mathrm{d}T} = 0 \quad (\text{for } T = 0).$$
To resolve this contradiction, Nernst referred to Planck's quantum theory, which predicted a deviation from the classical formula at very low temperatures. In his 1916 essay *On an Attempt to Return to Continuous Energy Variations from Quantum Theoretical Considerations* Nernst transferred the properties of Planck's black body radiation to the zero-point energy of the postulated luminiferous æther. With this model he was—among other results—able to explain why the electron in the ground state does not emit radiation, a paradox in Rutherford's model of the atom which was formally solved by Bohr's postulates in 1913. However, these were only an *ad hoc* assumption and hardly explained what really happens in the atom. (It took another decade until Bohr's postulates could be derived from the recently developed quantum mechanics.) Nernst, however, proposed a real explanation: In the ground state, he argued, the electron is in thermodynamical equilibrium with the zero-point energy, which provides the energy needed for its motion around the nucleus, an idea which was adopted much later by de Broglie when he proposed a *milieu subquantique* with which elementary particles are in permanent energy exchange (Louis de Broglie: *La Thermodynamique de la particule isolée*, Paris 1964, p. 101).
3. It is of interest from the point of view of modern cosmology to note Nernst's strategy of argumentation: to explain a microphysical phenomenon (the non-radiating electron) he makes an assumption with cosmological significance (the existence of vacuum energy in the æther). But his insight turns out to be even more revolutionary. Nernst was apparently the very first scientist who attributed black body radiation to the æther, and even attempted an approximate calculation of its energy density. In the sense of Nernst's assumptions, this radiation is not identical with the 3 K radiation. Instead, it corresponds to the modern concept of the vacuum density represented by the cosmological constant of General Relativity.
4. In its content, the "luminiferous ether" closely resembles the vacuum in today's quantum physics. In the vacuum, virtual particles are born spontaneously from the zero-point energy. When the vacuum is also understood as the medium that absorbs the energy of stellar and galactic radiation, the two conceptions become almost indistinguishable.
5. The extremely high value of U_o given by Nernst for the ether, and common also to modern conceptions of the vacuum, is unlikely given the low value of H and the transparency of space up to high z-values. *Cf.* The energy density of the CBR at 0.25 eV cm^{-3} = 4×10^{-34} g cm^{-3}. In the opinion of one of the editors (T.J.), the ether may simply contain the electromagnetic and

gravitational quanta, in which case U_o would be of the latter order of magnitude.

6. With a modern, ten times smaller value of H than that estimated by Hubble, the luminosities must be multiplied by one hundred.
7. It is uncertain whether the topic of dark matter was introduced independently by Nernst or adopted from Zwicky, who was the first to emphasize this problem, during the thirties; it came back into fashion 3 to 4 decades later.
8. At the start of this section, which need not be reproduced here, Nernst considers the Herzsprung-Russell main sequence as an evolutionary series for stars. The standard view today is that this sequence, which covers a considerable range of masses, follows from the initial mass function.
9. In this excerpt, we see an implicit prediction (1921) of the redshift effect and a solution, still valid today, of the de Cheseaux-Olbers paradox. In predicting the redshift, Nernst precedes the alternative “predictions” of Friedmann (1922) and Lemaître (1928), while in the case of the Olbers paradox, he anticipates more recent theories of the finite brightness of the night sky.
10. The energy degradation law developed by Zwicky and Nernst is often a decisive part of modern tired-light theories, which are mainly based on the law $\dot{H} = -HE$. One of the authors (*P.H.*) has proposed a closely related Retarded Light model (RLM). In the RLM we have $\dot{c} = -Hc$ (see *Apeiron* 14, 1992, 15 and *Apeiron* 18, 1994, 5) and $\dot{l} = c$, which follows as a consequence. After differentiation of the energy-wave-relation $E = hn = hc/l$ we have $h\dot{c} = \dot{E}l + E\dot{l}$. With $\dot{c} = -Hc$ and $\dot{l} = c$ we obtain $E = -(c/l)(hH + E)$ When we consider the energy degradation process of the whole Universe, we have to set $l = c/H$ and get $E = -H(hH + E)$.
11. For modern values, divide H and multiply distance both by a factor of 10.
12. This is an “almost-prediction”. Non-Doppler redshifts cause the north-south asymmetry of the rotation curve of the Milky Way, and as a consequence, the apparent distortions of the structural maps of the galaxy constructed by the kinematical method (Jaakkola et al. 1984). The redshift effect was actually observed first in the stellar spectra long before the discovery of the cosmological redshift (1929). The K-term of O and B type stars was discovered about 19??.
13. With $H = 60\ \mathrm{km\ s^{-1}\ mpc^{-1}}$, $hH = 1.4 \times 10^{-65}$ g.
14. Since Nernst did not know how to treat the hH term, he neglected the elementary energy quantum compared to the high energies in E. And indeed, with $hH \ll E$ we have $hH \cong 0$, and thus obtain Nernst’s energy degradation law. Concerning the hH term, in his paper *Further Applications of Physics to Stellar Evolution*, Nernst wrote:

    > *... hH therefore has the dimension of an energy quantum* ($= 1.2 \times 10^{-64}$ *erg), which we presently do not know what to do with because of its extremely small size. It may, however, later play a role as the elementary energy quantum (Urquant) in a theory of the zero-point energy of the Universe (luminiferous æther) (p. 479).*

15. The analysis of the difference between Hubble’s linear redshift-distance law, $z = (H/c)r_H$ and the tired-light law $\ln(1+z) = (H/c)r_t$ indicates Nernst’s perspicacity in scientific matters. Many later discussions of the relation lack this strictness. With increasing z, r_H increases faster than r_t: at $z = 0.1$, $r_H/r_t = 1.05$; at $z = 1$, 1.44; and at $z = 10$, 4.17. The difference is not observed directly in the brightness-redshift relation, for which a naive application of Hubble’s law gives $m_H = 5\log z + K(z) + C$, which is numerically practically the same as the tired light relation $m_t = 5\log\ln(1+z) + 2.5\log(1+z) + K(z) + C$. However, the distinction can be directly observed in angular diameter and surface brightness tests.
16. By “catastrophe theory”, Nernst means the nowadays standard idea of galactic formation at a particular early epoch of the big bang.
17. Actually, the opposite is supposed by the standard theory of stellar evolution.
18. For the standard model, with $H = 80\ \mathrm{km\ s^{-1}\ Mpc^{-1}}$ (the value given greater weight) and $q_o = +1$ (the value obtained from the (m,z)-diagram), to $\approx 10^{10}$ years. Again, this is smaller than, or uncomfortably close to, the age of the oldest stars.
19. Nernst is one of the first authors to signal the cosmological evolution of colour (and other properties) as a necessary consequence of the expansion hypothesis. Since the 1970s, this has become one of the most widely discussed topics in astronomy. Colour evolution is—together with number evolution of QSOs—currently the most strongly argued cosmic evolution effect; however, both have been contested as results of selection effects.
20. In modern terms, 18 billion.
21. Here Nernst overlooks an interesting line of argument. Absorption by cosmic dust only works for a while, until a radiation balance has been established. Then the dust would emit the same amount of radiation as it absorbs. Because Nernst presumed a temporarily invariant universe, there would be no good argument why the radiation balance had not been established long ago. Olbers’ paradox would remain. The same holds for the tired-light energy degradation by the ether; the paradox is only solved by the hypothesis of matter creation from the redshift energy absorbed by the ether.
22. Another joint solution of the two paradoxes (the de Cheseaux-Olbers paradox of the infinite brightness of the sky and the Seeliger-Neumann gravity paradox, called by Nernst the “cosmological paradox”, was recently suggested by Jaakkola. While Nernst obtained the solution (Equations I and II) through the ether hypothesis, in the latter the same formulae are obtained via the hypothesis of electrogravitational coupling. There is a difference only in the meaning of the ether. In both approaches, a solution to the third major paradox, the heat death, is implicitly present.
23. This relation was known long before Nernst’s publication. It was first noted by the astronomer Hugo von Seeliger in 1909, with the substitution of a “cosmological constant” l for H/c in the exponent. In this law of absorption of gravitational force with distance Seeliger saw a solution to the gravitation paradox of an infinite Universe. That Nernst did not know Seeliger’s relation seems unlikely, since he was acquainted with Seeliger himself and his son Rudolf, a physicist in Greifswald north of Berlin. (Perhaps Nernst did not realize that $\sqrt{\Lambda} = H/c$ in some cosmological models. In particular, the square of Seeliger’s Λ is equal to Einstein’s cosmological constant l.)
24. Nernst deduced the identity of chemical and physical forces, such as the weak force and gravitation, in the vicinity of absolute zero in his 1916 study of quantum theory. He states:

    > *The work generated by gas expansion, the force of cohesion of chemical force [i.e. electromagnetic force, editor], radioactivity, the Newton force, etc., are all identical processes at low temperatures, since the zero-point energy is constantly being converted into external work. The difference is that different kinds of zero-point energy (defined by the corresponding molecular, atomic or interatomic oscillations) are converted.*
    >
    > *Accordingly, all these processes are subject to an influence of temperature that is, in principle, analogous and thermodynamically quantifiable (via the heat theorem). This calculation has been performed for gravitation.*

    A unification of physics at the zero-point energy certainly seems more plausible than the converse, *i.e.*, unification at the extremely high temperatures of the hypothetical Big Bang.
25. In his 1916 study, Nernst noticed that the assumption of a luminiferous æther would, in principle, make it possible to measure absolute motion in space. However, he argued that frequency and time dilation of a system would handicap an observer.
26. The theoretical aspect involved in Equation (III) is important and “new” even for today. Large absolute motions of galaxies, their clusters and even second-order clusters are presently commonly assumed as derived from the redshift data and the CBR dipole anisotropy. However, improper analysis remains a noteworthy

possibility here. As another topical observation, the quantized character of the galaxy redshifts established by Tifft and Arp, and confirmed by Guthrie and Napier leaves little room for large absolute velocities, and hence may be evidence in support of Nernst's ideas and his Equation III.

27. The current, obviously well-founded paradigm of element formation is that all elements except the lightest ones are products of fusion processes in stellar interiors (up to iron) and in supernovae explosions (the rest). The case that part of the elements would be processed directly in space remains an interesting possibility.
28. In modern astrophysics, heavy elements are fused in nuclear reactions within stars. Evidently, the creation of heavy nuclei in the ether suited Nernst's general picture in accordance with the second law and radioactive decay, which were popular issues of the time.
29. With matter/energy equivalence and modern estimates of luminosity density $\Im$, one obtains $c_m = \Im / c^2 = 3\times10^{-53}$ g cm^{-3} s^{-1} = 1 neutron in a lab per 10^{14} years. This is smaller than Nernst's value by a factor of 10^5, and the same size as the energy density of cosmic rays, with E > 10^{18} eV, usually assumed to make up the extragalactic background that cannot be trapped by the magnetic field of the Galaxy. See also Nernst's footnote to the second paragraph following and beginning of §9.
30. This is a very notable prediction, made three decades before the actual observation of the CBR, which possesses a similar universal energy density to the local energy density of starlight and similar to some other local components of the cosmic energy density.
31. Rather, it may be that $T >> 1/H$ for many galaxies. Galaxy formation is, in a sense, a continuous process, with matter infalling into them from the outside, and evolution may contain many cycles of morphological and physical development. However, the lifetime of a galaxy is limited by its evolution as a dynamical unit in the larger system.