On an attempt to return from quantum theoretical considerations to the assumption of continuous energy changes;

by W. Nernst.

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Contents: Introduction. §1. Basic principles. §2. Generalization of the law of equal energy distribution. §3. Radiation, specific heat, chemical equilibrium. §4. Model of the hydrogen molecule. – Appendix – Summary.

Designations and numerical values (cgs).

Speed of light .... $c = 3.00.10^{10}$.
Planck's constant .... $h = 6.55.10^{-27}$.
Gas constant .... $R = 8.315.10^{7}$.
Number of molecules per Mol $N = 6.17.10^{28}$.
Mass of the Hydrogen atom . $m = 1.63.10^{-24}$.
Mass of the negative electron $\mu = 8.9.10^{-28}$.

$$k = \frac{R}{N} = 1.847.10^{-16}$$

ν .... Vibration frequency.
$\epsilon_0 = h\nu$ .... Elementary quantum of energy.
T .... Absolute Temperature.
$\beta\nu = \frac{h\nu}{k}$ .... Specific Temperature.
V, v .... Volume; v in the appendix: velocity.

As is well known, PLANCK's quantum theory has led modern physics and physical chemistry to a very large number of new insights and discoveries, so its fruitfulness is beyond question.

On the other hand, these enormous advances have been bought with heavy sacrifices, if one may express it this way. The basic law of mechanical heat theory, the law of equal Energy distribution had to be abolished or at least restricted to a limiting law valid only for high temperatures; the principles of electrodynamics and mechanics in general can only be applied to atoms with reservations, and the general usability[1]) of our most important logical tool, the differential equation, is called into question.

The hope I had in mind when I made that suggestion, which Mr. Solvay responded to in such a unique way at the time, namely that the gap described could be bridged by consultation in circles of the most outstanding experts, has indeed been fulfilled insofar as since then many of the best theoreticians and experimentalists have devoted their full energy to the subject, but the core of the question has remained unexplained. There has been no lack of attempts[2]) to return to the concept of continuous energy changes, but there is agreement that all these attempts have not produced a replacement for the quantum theory. We should by no means call these attempts useless, since taken as a whole they certainly lead us to the following conclusion: without a completely new fundamental hypothesis, real progress is not conceivable, and it is in the nature of things that such a hypothesis would not only have to replace quantum theory, but would also have to lead us beyond it in many ways.

I would not have made the following considerations and calculations, whose partly provisional character may be excused both by the difficulty of the subject and by external circumstances, public if it did not appear that the path I have taken would lead to new knowledge, even about questions that lie far removed from existing quantum theory.

On the other hand, I would like to point out an important gap in the following considerations. The theory of line and band spectra, for which BJERRUM, BOHR and others have given highly noteworthy aspects with the help of quantum theory, will remain undecided here for the time being. It is one of the peculiarities of quantum theory that some very strange relationships result from a simple approach, which is often not free from arbitrariness[1]). The strict and consistent treatment of

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[1]) See especially H. POINCARÉ, Journ. de physique (5) 2, 6, 1912.

[2]) I have found particularly valuable advances in two works, which I would like to mention here: S. RATNOWSKY, Proceedings of the D. Physik. Ges., No. 4, 1915; EINSTEIN and STERN, Ann, d, Physik 40, 551, 1913.

[1]) See F. A. LINDEMANN, Proceedings of the D. Physics. Ges. 16, 281, 1914.

radiation phenomena resulting from electron movement within atoms will perhaps be possible later on with the help of the following considerations, but will hardly be simple.

§1. Basic principles. I. In my general lecture delivered in 1912 at the Natural Scientists' Meeting in Münster, I pointed out that the phenomena of radioactivity, which are connected with a continuous "degradation of matter" (alongside the continuous "degradation of energy" required by the second heat law), require some reciprocal phenomenon if we want to hold fast to an arbitrary duration of the universe; We can also add that, in view of the continuous production of helium by radioactive processes, even if the universe has a finite but very long existence, helium would have to be a very common element. This makes the existence of a phenomenon in which helium disappears, either by dissolving into the blocks of the luminous aether, from which, as I previously assumed, from time to time, but as can easily be estimated, very rarely, an atom of a (probably highly atomic) element emerges, or by helium atoms polymerizing to form one from time to time. The following considerations now lead in fact, as I previously suspected, to an enormously large energy reserve stored per cubic centimetre in the luminous aether; the new production or rearrangement of atoms is thus brought closer to understanding. I will not return to these questions, which are not yet accessible to a purely physical approach; they were mentioned here briefly because they helped to make the hypothesis now to be discussed more plausible to me from the outset.

II Magnetic and especially radioactive phenomena already convincingly demonstrate that we must assume internal movements in material structures even at the lowest temperatures, and that absolute zero does not mean the end of all movement. Recently, the old concept of the absolute zero point has been broken even more radically by PLANCK's highly original introduction of zero point energy. At first, however, I found it difficult to believe in such a zero point energy, which evidently has nothing to do with heat and about whose origin I had no idea. I was also disturbed by the further consequence that an electron oscillating or, more correctly, orbiting due to its zero point energy cannot emit radiation, and that classical electrodynamics should therefore also fail in the area of small dimensions. These difficulties disappear if the previous hypothesis of zero-point energy is expanded in the following way: Even without the presence of radiating matter, i.e. matter heated above absolute zero or otherwise excited, empty space or, as we would rather say, the luminous aether, is filled with radiation; the spatial energy density of the oscillation number is given by the equation:

$$u_0 = \frac{8\pi h}{c^3}\,\nu^3. \qquad 1)$$

According to known principles, an electron that is suitably bound by quasi-elastic forces and vibrates linearly then absorbs the energy

$$E_0 = h\nu$$

An electron oscillating in this way does nothing other than bring itself into equilibrium with the zero-point radiation; the laws of electrodynamics are not only not violated, but the zero-point energy is established according to the laws of electrodynamics.

A principle which I have occasionally formulated[1]), but which has probably been tacitly generally accepted even earlier, states that an uncharged atom behaves exactly like a charged atom or electron with regard to thermal motion; accordingly, every atom and every conglomerate of atoms which, due to its mechanical conditions, is capable of oscillation at the rate per second, will absorb the kinetic energy

$$E_0 = \frac{h\nu}{2}. \qquad 2)$$

per degree of freedom, and, as already noted, at absolute zero.

We do not know whether radiation has a direct ponderomotive effect on individual atoms; it should only be emphasized that such an effect can be arbitrarily small. The magnitude of such a force is only decisive for the speed with which the stationary state is established, not for the amount of energy ultimately absorbed, which is the only thing that matters here. But even if such a force did not exist, we would have to imagine that primarily the building blocks of the atoms, the positive and negative electrons, begin to oscillate in accordance with their respective ν values, and that this brings the energy of the oscillations of the centre of gravity of the atom into equilibrium. The end result, namely that matter and electrons must come into equilibrium, is beyond doubt.

[1]) ZS. f. Elektrochemie 1911, p. 269.

In contrast to ordinary thermal motion, but in accordance with thermodynamics, zero-point energy, like any other energy at absolute zero, is free energy.

Already this fact causes a significant difference between ordinary thermal motion and ordinary radiation energy on the one hand, and zero-point motion and zero-point radiation on the other. The most important future task will be to clarify these differences further. First of all, the simplest assumption will be to consider the zero-point energy as ordered in comparison to the heat energy. I do not see a way to establish the general distribution law of the fluctuations of the zero-point energy (see below).

It will be useful to formulate more precisely the differences between the PLANCK zero-point energy and the zero-point energy assumed by me.

1. PLANCK's hypothesis referred only to vibrating structures, mine also refers to the intermediate medium.

2. For quasi-elastically vibrating structures, the energy I assume is twice as large, in all other cases in which which initially remained undetermined in PLANCK's work, can be calculated according to the laws of statistical mechanics by simply substituting $h\nu$ for kT.

3. Special new assumptions about emission, absorption and Electrodynamics are now unnecessary.

4. If one imagines a resting, oscillating structure at absolute zero, it would remain at rest according to PLANCK, and in my opinion would absorb the given amount of zero-point energy from the light aether.

5. According to PLANCK, the law of conservation of energy remains valid at all times and for every atom; in my opinion, one could break it as often as one likes using the method described under 4., by extracting as much energy as one likes from empty space. If one includes light in the system, the energy principle naturally remains in force.

6. The law of conservation of energy in its current form, like the second heat law, now also has a statistical character. However, all previous experiments that have been carried out to test the above law

naturally had to turn out the way they did in accordance with my theory, because average values were always measured.

III. If one were to assume that the ν^3 law applies up to arbitrarily high vibration numbers, the energy content of the light aether per cubic centimetre would be infinitely large. In itself, I see no reason to present this view as impossible, because in order to communicate with such infinite amounts of energy, we would have to have particles with an infinitely high vibration number, and that is simply not the case. In practice, these amounts of energy do not exist for us.

After all, such an opinion runs counter to our gratitude. Therefore, I prefer the following hypothesis (which is irrelevant for what follows). The intermediate medium is also [as I always assumed[1])] of atomistic structure; however, this means that the Oscillations must stop at a certain number. Instead of 1), a law of the form

$$u_0 = \frac{8\pi h\nu^3}{c^3\nu_0}\,\frac{\nu}{e^{\frac{\nu}{\nu_0}}-1} \tag{3)}$$

will then take effect. It is uncertain whether the constant ν_0 (or the corresponding one of the true law) plays a role in any of the phenomena observed so far; it is possible that it enters into the constants of NEWTON's or COULOMB's law[1]). In any case, it would be of the greatest importance to obtain a third value ν_0, in addition to c and h, for the characterization of empty space – because h is also a characteristic quantity for the light aether in the sense of the concept presented here.

Because of ignorance of ν_0, we cannot estimate the total energy of the radiation

$$U_0 = \int_0^\infty u_0\,d\nu$$

However, since we can assume that equation 1) remains valid up to the X-ray region, we can determine a lower limit for U_0 :

$$U_0 > \int_0^{\nu'} \frac{8\pi h}{c^3}\,\nu^3\,d\nu = \frac{2\pi h\nu'^4}{c^3},$$

[1]) See my Theoretical Chemistry, 7th edition, p. 426.

[1]) If this assumption were correct, all attempts to calculate the proportionality factor of these laws in absolute terms would fail at present, but the reduction of one force to the other would remain conceivable.

in which we $\nu' > 10^{20}$. The energy content per cm^3 is:

$$U_0 > 1.52 \,.\, 10^{23}\,\mathrm{Erg} = 0.36 \,.\, 10^{16}\,\mathrm{g - cal.}$$

The amount of zero-point energy present in the vacuum is therefore enormous, and extraordinary fluctuations in it are capable of having the greatest effect (see introduction).

IV. As already clear from the preceding, we have arrived at the zero-point energy $h\nu$ and for the zero-point radiation therefore at a ν^3-law. Now such and only such a law shows Radiation has the striking property that in the equation[2]):

$$\delta u = \left(\frac{\nu}{3}\frac{\partial u}{\partial \nu} - u\right)\frac{\delta V}{V} \tag{4)}$$

the right-hand side disappears, i.e. the spatial energy density of any oscillation number does not change during compression [incidentally, this result remains valid for the radiation accessible to us, even if we calculate with equation 3]. This conclusion is important and makes it possible to maintain the view presented here.

All doubts that one might have against zero-point radiation because of radiation pressure or because of the resistance of bodies moving in a vacuum are eliminated by this certainly remarkable result; only by using mirrors that are also effective for very short-wave radiation would zero-point radiation become apparent.

It should be noted that the ν^3 law for zero-point radiation is not an ad hoc hypothesis, but rather it results from the fact that we introduce h for kT into the formulas of classical statistical mechanics, and accordingly make the same substitution in RAYLEIGH's radiation formula[1]), i.e. we must insert the expression $h\nu^3$ for $\nu^2 kT$.

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[2]) PLANCK, Heat Radiation, 2nd ed., p. 80.

[1]) Historically, it should be remembered that Lord RAYLEIGH (Phil. Mag. of July 1900) set the radiation only proportional to $\nu^2 T$; the full expression $u = \frac{8\pi\nu^2}{c^3} kT$ was only given by PLANCK, so that one should speak of RAYLEIGH-PLANCK's law.