and bacteria would produce this compound, easily recognisable by its colour. So, if later it should be proved that the manganese moulds really produce a substance causing oxidation out of the cells, it may now already be asserted that it can neither be oxidase nor chinon.

From the preceding we see that with the oxidation of mangano-carbonate by microbes, many questions are related, worth a nearer examination, especially with regard to the conversions which these very common microbes cause in the soil.

Physics. — *"On the law of partition of energy."* IV. By Prof. J. D. VAN DER WAALS JR. (Communicated by Prof. J. D. VAN DER WAALS.)

§ 12. In my previous communications on this subject I started from the earlier formula of PLANCK, in which no zero-point energy was assumed. In fact the assumption of zero-point energy involves great difficulties. In my opinion the supposition that a vibrator vibrating with slighter energy than νh would not emit energy [1]) is not so much responsible for these difficulties — something similar would already be found in a charge, which moved in a perfectly conducting inclocure — but rather the assumption that radiation coming from the outside yet acts on the electron in a normal way, and sets it vibrating. [2])

In spite of these difficulties PLANCK's later formula for the energy of a vibrator has of late been preferred by different physicists. The quantitative grounds adduced for this, seem to be still pretty un-

[1]) Strictly speaking it might be said that PLANCK's vibrators in a certain sense do radiate, also when they contain less energy than a quantum. For they absorb energy, and absorption is a kind of emission. If e.g. we imagine a source of light and a black screen and investigate the light behind the screen by means of electro-magnetic potentials, we find darkness there, only because the contributions to those potentials, yielded by the electrons of the screen, just cancel the contributions furnished by the electrons of the source of light. If the electrons of the screen did not emit potentials and forces derived from them, we should have to observe the direct light of the source behind the screen. So PLANCK's supposition does not really come to this that vibrators when they do not possess exactly a whole number of quanta, do not radiate, but that they radiate in a particular way unilaterally.

[2]) It is remarkable that it is assumed here that the elementary process of absorption is not reversible, whereas by the cooperation of many suchlike processes reversible observable phenomena do originate.

certain as yet. Thus EHRENFEST[1]) could account for the course of the specific heat of hydrogen without assuming zero-point energy, whereas EINSTEIN and STERN[2]) derived from this course a proof for the existence of zero-point energy.

I will now draw attention to a phenomenon, which, so far as I know, has never been considered in the light of a possible existence of a zero-point energy[3]), and for which it seems very difficult to account even qualitatively without the assumption of zero-point energy. This phenomenon is the radio-activity. A radio-active atom, namely, which has continued to exist unchanged for a long time, suddenly explodes. So something must have been modified, either in the atom itself, or in its surroundings. If no zero-point energy is assumed, no movement would be present in the atom which follows from the value of the specific heat. Accordingly nothing would change there. With thermal equilibrium, however, the changes in the surroundings are determined by the thermal motion; they seem, therefore, unable to explain the appearance of radio-active phenomena, as they are independent of the temperature. Thus no circumstance governed by chance is found on which the setting in of a radio-active explosion of an atom could depend.

Matters are different if it is assumed that several particles vibrating with a high frequency are present in the atom. On account of the high frequency they will possess no thermal energy, but only their zero-point energy. So this energy can manifest itself neither by radiation, nor by a contribution to the specific heat. If it is now assumed that the different particles have different frequencies, and that they exhibit different amplitudes (varying from o to νh) and phases in different atoms of the same kind, a circumstance is given in their motion, which renders the setting in by chance of a definite unstable configuration of the particles of the atom possible, and thus leads to a radio-active explosion. Then the energy of the radio-active rays and of the generation of heat might be found from the zero-point energy. A change in potential energy might also contribute to this, but so far as we know this might be as well positive as negative, and the supposition would naturally suggest itself that the

1) P. EHRENFEST, Verh. d. D. phys. Ges. 1913, S. 451.

2) EINSTEIN and STERN. Ann. d. Physik IV, 40, 551, 1913.

3) Note added in the English translation, when I was correcting the proofs. As Dr. KEESOM was so kind as to point out to me, I was mistaken when I thought that this interpretation of the radio-active phenomena had not been given before. It was already given by PLANCK himself. Vorlesungen über Wärmestrahlung, 2nd ed. p. 140.

potential energy of the formed products is greater than that of the atoms before the decomposition, so that this increase of potential energy too would have to be accounted for by the zero-point energy.

Such a supposition of particles moving with great velocity in the radio-active atom has been made already before. But considered without connection with the zero-point energy it seemed too arbitrary, and HAHN and MEITNER's and VON BAYER's experiments, which showed that the β-rays of a certain radio-active atom are homogeneous, seemed to point to a definite loss of potential energy of the emitted particles, which was found back in the form of kinetic energy [1]. This homogeneity of the rays, however, might now be explained in a different way, viz. by assuming that a particle that vibrates with a period ν in the atom, is also emitted with an energy νh. Then there would be a close correspondence between radio-activity and the light-electric effect. The difference between the two phenomena would only consist in this, that for the latter light falling on the atom from the outside, for the former cooperation of the different intra-atomic motions gave rise to the emission.

According to this supposition the frequency of the internal vibrations for β-rays emitted with a velocity $v = 0{,}92$ c. would have to be estimated at $\nu = 8{,}25 \times 10^{19}$.

SOMMERFELD [2]) calculates $\lambda = 6 \times 10^{-11}$ for the γ-rays with this velocity of the β-rays, which corresponds to $\nu = 5 \times 10^{-20}$. Hence the period of the internal vibrations according to this supposition would have to be somewhat greater than corresponds with the wavelength of the corresponding γ-rays. At any rate the value which we find in this way for the frequency is so great that even at the highest temperatures attainable we are very far from the point at which, according to PLANCK's formula, we could expect any perceptible change in the energy of the motions, so that the otherwise so unaccountable fact that not the slightest influence of the temperature is found on the radio-active phenomena is very satisfactorily interpreted.

Perhaps little weight should be attached to such not quantitatively testable considerations. I myself also doubt whether they supply a sufficient ground to justify us in adopting a zero-point energy in spite of the difficulties which attend it. Yet I have thought I ought to point out the advantages which it offers.

[1]) It is perhaps also possible to retain this view, and only add to it the assumption that, in order to be able to be emitted, a particle must beforehand have been brought by the zero-point motion in such a position of maximum potential energy that it is shot out from there with that definite energy.

[2]) SOMMERFELD. Congres Solvay, 1911, p. 342.