The Concept of Light Molecules and Light Multiples: A dead-end Way to simulate Bose-Einstein Statistics for Black Body Radiation

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Abstract:

In 1900 Max Planck obtained by rather "*obscure means*"[1] the radiation formula for the energy density (energy per unit volume and unit frequency interval) of black body radiation: $u_\nu = (8\pi\nu^2/c^3)[h\nu/(e^{h\nu/kT}-1)]$. It fitted over the whole frequency-temperature range the data of that time perfectly. The derivation of the two factors in this equation bears quite different problems. Whereas the first one is connected to the dynamic of the oscillators within the black body radiator, the second one derives from the combinatorial assumptions on the distribution of the energy levels of the oscillators. It was only Bose who put the derivation of both factors on a common footing.[2] In this note we concentrate on the interpretation of the second factor only. Additionally we will report on the relationship of the two main actors, M. Wolfke and W. Bothe, to Einstein.

Historically it was Einstein himself who opened the game by demonstrating that in the Wien-limit black body radiation behaves as a dilute gas consisting of light quanta.[3] The energy of light appeared in some kind of granular structure. Following his own preparatory work[4] and that of A.F.Joffe and J.Stark, M. Wolfke from Zurich, who had close connections to Einstein, concluded on pure formal grounds that black body radiation may consist of spatial independent "light molecules" with energies shν, s=1,2,3,... .[5] (Planck's formula can be expanded as $u_\nu = \sum_{s=1}^{s=\infty} u_{\nu,s}$, with $u_{\nu,s} = (8\pi\nu^2/c^3)h\nu e^{-sh\nu/kT}$.) L. de Broglie while discussing briefly Einstein's fluctuation formula, offered a year later a similar interpretation.[6] On the other site Einstein himself always opposed to interpret in general light as being composed of independent quanta.[7]

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[1] O.Darrigol, A simplified genesis of quantum mechanics, SHPMP)40(2009)151-166
[2] S.N.Bose, Plancks Gesetz und die Lichtquantenhypothese, Z.Phys.26(1924)178-181
[3] A.Einstein, Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt, Ann.Phys.17(1905)132-148
[4] M.Wolfke, Zur Quantentheorie,Verh.DPG15(1913)1123-1129, 1215-1218
[5] M.Wolfke, Einsteinsche Lichtquanten und räumliche Struktur der Strahlung, Phys.Z.22(1921)375-379
[6] L.de Broglie, Rayonnement noir et quanta de lumière, J.Physique et Radium 3(1922)422-428
[7] See letters of Einstein to Wolfke, dated 12. July 1946 and of Wolfke to Einstein, dated 17.Aug.1946. We thank the son of M.Wolfke, Prof.Dr.Karol Wolfke,Wroclaw, Poland for copies of both letters.

Again a year later W. Bothe from Berlin, who had also close connections to Einstein[8] tried to understand Einstein's fluctuation formula from a dynamical point of view, analyzing the equilibrium conditions of black-body radiation in contact with two level molecules.[9] In order to introduce the concept of "quantum multiples" Bothe refers to the fact that e.g. in a stimulated emission process the inducing and stimulated quanta are perfectly correlated: "*The quanta are coupled seemingly; only seemingly, since in truth no forces exist between both, the dissociation energy ... is zero*". Even though Bothe arrives at identical expressions as Wolfke and de Broglie, his quantum multiples are quite different from the light molecules of Wolfke and de Broglie. Today one would call them probably "quasi particles". Bothe's ansatz proved to be useful when applied to a similar problem, the interaction of electrons with black body radiation[10], for which Pauli had to chose a rather unphysical ansatz for the rate of the Compton scattering processes in order to achieve equilibrium for the system.[11]

Nevertheless, Bothe rated the concept of light multiples as "*less fruitful"* after Bose's derivation of Planck' law appeared.[12] That is in contrast to Wolfke, who still sent in 1946 a manuscript dealing with "multi photons" to Einstein.[7,13]

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[8] D.Fick and H.Kant, Walther Bothe's contributions to the understanding of the wave-particle duality of light, SHPMP 40(2009)395-405

[9] W.Bothe, Die räumliche Energieverteilung in der Hohlraumstrahlung, Z.Phys.20(1923)145-152

[10] W.Bothe, Über die Wechselwirkung zwischen Strahlung und freien Elektronen, Z.Phys.23(1924)214-224

[11] W.Pauli, Über das thermische Gleichgewicht zwischen Strahlung und freien Elekronen, Z.Phys.18(1923)272-286

[12] W,Bothe, Zur Statistik der Wärmestrahlung, Z.Phys.40(1927)345-351, footnote 3 on p.346

[13] M.Wolfke, Über die Mehrfachquanten in der Planckschen Strahlung, Helv.Phys.Acta19(1946)437-429