From Relativity to the Photon

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Two widely different conceptions of electromagnetic radiation were compared by Einstein in his 1916 papers, namely, the classically diffuse form and the fully directional form. The emission process of each kind of radiation is examined hereafter from a relativistic point of view. The necessary covariance of any physical description, further specifying the original directional property, points to a strictly quantized form of radiation as the only one consistent with relativity, thus showing a deep relationship between this latter and quantum theory.

1. INTRODUCTION

Following Planck's quantum hypothesis, and at variance with Maxwellian Electrodynamics, Einstein (1) proposed the "heuristic point of view" according to which electromagnetic radiant energy could only be observed under a discontinuous form: "Lichquanten," as he named it.

Further study of this radiation problem confirmed Einstein's first idea, and in 1916–1917 he wrote several papers (2) on the same subject.

Analyzing the velocity distribution of corpuscles in equilibrium with thermal radiation in a closed volume, he obtained the formerly established Maxwell–Boltzmann law by making the following assumptions:

1. Radiant energy is quantized as \( h \nu \).
2. Emission by a source can be spontaneous, but also stimulated.
3. A radiant quantum's energy being \( h \nu \), its momentum is unidirectional and equal to \( h \nu/c \).

Einstein had started his demonstration by admitting that radiation could be either symmetrical or directional. The third assumption, which

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was compulsory in the calculus, led Einstein to conclude that classical spherical radiation, the *Kugelstrahlung* (KS), did not exist, the only possible form being the fully directional *Nadelstrahlung* (NS), i.e., needlelike radiation.

A few years later came a first experiment, which seemed to confirm the NS form of radiation interacting with corpuscles, by Compton and Debye.\(^{(3)}\)

Almost half a century later came another experimental proof of the fully directional character of electromagnetic radiation, but this time, in the process of emission. This was the direct observation of the recoil taken by emitting atoms.\(^{(4)}\)

Many further experiments showed the nonsplittable property of light quanta, even when classical wave theories predict a wide spreading of the radiant energy.\(^{(5)}\)

It has been shown elsewhere\(^{(6)}\) that even in the simple case of an isolated charged particle undergoing linear acceleration, the whole process of emission would contradict relativistic dynamics or covariance, if classical KS radiation was assumed. In this quite elementary phenomenon, as in the studies mentioned above, the only possible form of radiation is a fully directional NS.

The whole matter of radiation form has been somewhat swept under the rug in recent years, and all the processes of quantum electrodynamics can even be explained without quantization of the fields.\(^{(7)}\)

On the other hand, despite the severe blows it has endured, classical electrodynamics, which predicts KS radiation, still keeps its own logic unscathed, and does explain observations at the macroscopic level. Furthermore, Maxwell's equations are relativistically covariant, and, at first sight, the ensuing radiation scheme should also be relativistic. Relativity nevertheless does agree with Einstein's bold proposal of Lichtquanten. Any kind of energy has a limited propagation velocity, which would prevent its instant collapse in one point if it was initially widely spread out in space.

As already mentioned, relativistic dynamics and KS radiation are in contradiction, in certain cases at least.

A certain gap therefore seems to exist between Maxwell's equations and the classical KS description, and the reason for this discrepancy could be of relativistic essence. Even quantization of the sources does not appear as sufficient to give a satisfactory description of radiation as observable quanta, if a precise and realistic image is sought.

In an endeavor to better understand radiative phenomena, a thorough study of the two opposed KS and NS forms of radiation seems relevant, and will be carried out hereafter by simple relativistic methods.