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Quantum states of electromagnetic field interacting with a classical current and their applications to radiation problems

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Abstract

In the beginning, the synchrotron radiation (SR) was studied by classical methods using the Li\'{e}nard-Wiechert potentials of electric currents. Subsequently, quantum corrections to the obtained classical formulas were studied, considering the emission of photons arising from electronic transitions between spectral levels, described in terms of the Dirac equation. In this paper, we consider an intermediate approach, in which electric currents generating the radiation are considered classically, whereas the quantum nature of the radiation is taken into account exactly. Such an approximate approach may be helpful in some cases, it allows one to study the one-photon and multi-photon radiation without complicating calculations using corresponding solutions of the Dirac equation. We construct exact quantum states of the electromagnetic field interacting with classical currents and study their properties. By their help, we calculate a probability of photon emission by classical currents and obtain relatively simple formulas for the one-photon and multi-photon radiation. Using the specific circular electric current, we calculate the corresponding SR. We discuss a relation of obtained results with known before, for example, with the Schott formula, with the Schwinger calculations, with one-photon radiation of scalar particles due to transitions between Landau levels, and with some previous results of calculating the two-photon SR.

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