12

Summary and preamble to the quantum theory

Within the framework of specific models for the coupling between charges and the electromagnetic field we have presented a fair amount of rather detailed arguments and computations. Thus before embarking on the quantized theory, it might be useful to summarize our main findings.

- *Extended charge*. To have a well-defined dynamics, a smeared charge distribution has to be used. This can be done either on the semirelativistic level of the Abraham model or in the form of a relativistically covariant theory, i.e. the Lorentz model. In the latter case internal rotation must be included by necessity.
- *Adiabatic regime*. Situations for which the classical electron theory can be experimentally tested fall in the adiabatic regime with a remarkable level of accuracy. Quantum mechanics must be used way before one leaves the domain of validity of the adiabatic approximation. A good example is the hydrogen atom in a bound state. Sufficiently far from the nucleus, which is certainly satisfied when at least a Bohr radius away from it, the assumptions for the adiabatic approximation are fulfilled and the dynamics of the electron is well governed by Eq. (9.14). On the other hand, it is known that the fluorescent spectrum of the hydrogen atom is accounted for only by quantum mechanics. To test the classical electron theory on the basis of this system is simply not feasible. Thus, in the range where the classical electron theory is applicable by necessity one is inside its adiabatic regime. In this regime the particle becomes point-like and is characterized by a charge, an effective mass, and, in the case of internal rotation, by an effective magnetic moment; compare with sections 4.2 and 10.1. From the full charge and mass distribution, which in principle constitute an infinite number of free parameters, only a few of their low-order moments are retained. They then enter in the Landau–Lifshitz equation (9.10), which governs the motion of the charge with great precision and properly accounts for friction through radiation. In addition,

the electromagnetic fields are determined from the Liénard–Wiechert potentials as generated by the motion of a point charge.

- *Point-charge limit*. As judged from the context of chapter 28 of the *Feynman Lectures*, "consistency" in the 1963 opinion of R. Feynman, compare with the citation at the end of section 3.3, refers to the point-charge limit $R_\varphi \to 0$. I agree, but as argued at length there is no need ever to take this limit. Letting the size R_φ of the extended charge distribution shrink to zero yields objects of infinite mass. While the mere mathematical operation is admissible, it would result in a theory with very little physical content. The attempt to compensate through a proper adjustment of the bare mass fails, since the electromagnetic mass merely adds to the bare mass. Thus, the bare mass necessarily becomes negative which results in an unstable Hamiltonian.

The transition to the quantum theory of photons, electrons, and nuclei could hardly be less spectacular. I find it truly amazing that the simple rules of canonical quantization work so well for the Abraham model and thus open the gateway to a theory describing a vast territory of physical experience. Of course, just as the Abraham model, the theory is semirelativistic, and is thus also known as nonrelativistic quantum electrodynamics. No quantization of the Lorentz model seems to be available. In the relativistic domain one has to rely on conventional quantum electrodynamics.

We continue to adhere to the principle of restricting our attention to dynamical problems, for which the interaction between the charged particles and the photon field must be included. In particular, the emission and absorption of light by atoms and the scattering of photons from charges will play an important role. Adiabatic-type limits will be studied again. They show up in the limit of slow motion, where the photon field is approximated by the static Coulomb interaction, and in the derivation of the effective mass and the effective magnetic moment. To keep the topics within manageable size, many things had to be left out. In terms of applications the most serious omission is macroscopic electrodynamics, where the photon field is treated in the classical limit and matter is taken into account in a continuum description in terms of suitable electric and magnetic susceptibilities. Needless to say, they must be based on an atomistic quantum model of matter.