

Preface

Electromagnetic field carries the bulk of information about the structure of matter, atoms and molecules, nuclei or even elementary particles. Theory in this respect has the basic task: to retrieve this information from the available data that are obtained from experiments. The task is, therefore, finding a connection between the density of charges and the intensity of emitted radiation that they produce when subjected to external agitation; in short the task is solving the inverse intensity problem. However, the task as described is not that simple, although the problem of direct inverse intensity problem is immensely difficult one to solve. Charges that one discusses are basically electrons and protons, or their conglomerates, but they are quantum objects for which the concept of charge density must be fundamentally modified from that for classical charges. Electrons and protons are individually, as classical objects, point-like charges but as quantum objects they must be treated as delocalized particles and therefore treated as charge densities. The problem, however, is more difficult than that, because being treated as delocalized particles they are described essentially by probability densities and therefore by assuming that as charge densities must be taken with great caution. There are circumstances when probability density could be treated as charge density but there are when this is not a correct assumption. The choice when and how to distinguish between these two concepts, probability density versus charge density, depends on the problem to analyze, which is also sometimes not a simple task.

There are essentially four problems to analyze in electromagnetic interactions. One is dynamics of charges under the impact of electromagnetic force, another is radiation that is produced by moving charges, the third is structure of conglomerates of charges, and the fourth is the problem of field interaction, essentially unification of electromagnetic force and the force that results from radiation. All of these problems have been thoroughly studied, perhaps with exception of the last one, however, extreme states under which charges are placed, extreme states of electromagnetic field that interact with charges and fine details of this interaction have room for further investigations. Placing the field and charges under extreme conditions requires theoretical tool that adequately could describe these situations.

Relativistic classical and quantum theory are the foremost tools, description of electromagnetic field of finite extent in all dimensions, and also having accurate description in nonrelativistic theoretical tools.

Electromagnetic field itself is also essential to be understood because this has direct impact on how from experiments one interprets structure of matter. The basic principles of electrodynamics are well established, but with the development of quantum principles and applied on the scale of atoms and smaller another of its feature emerged, which is universally accepted: electromagnetic interaction is mediated by photons, manifestation of particle-like interaction on charges. Origins of the idea for the particle nature of electromagnetic field go back to explaining black body radiation, photoelectric effect, and finally the Compton effect. Success of the model is undisputable but there are limitations on how far it could be applied, for example in the case of very strong electromagnetic fields. There is an obvious question and this is what is the true nature of the photon model, because despite successful in explaining many features of matter there are some limitations of it, for example in interpretation of the Coulomb law as exchange of photons among charges. The answer to this question is not yet clear, and it should be found with in-depth understanding of solutions of the basic equations of dynamics: Dirac and Maxwell equations, coupled with the relativistic classical equation for particles.

Those four mentioned problems are investigated in this book, by giving qualitative description to get their essence before applying exact tools and these are equations for electromagnetic field and both classical and quantum dynamics, and relativistic and nonrelativistic, for charges. Separate discussion is on equations for relativistic dynamics, Maxwell and Dirac equations, as the essential tools for investigating the charges under extreme confinements and their interaction with the electromagnetic field. The basic tool for describing photon interaction with matter, quantum electrodynamics, is not used; however, it is mentioned in the context when the particle-like exchange of electromagnetic interaction is encountered.

Zagreb, Croatia

Slobodan Danko Bosanac

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Bosanac, S.D.

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