Quantum electrodynamics of strong fields

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W. Greiner, B. Müller, and J. Rafelski. *Quantum Electrodynamics of Strong Fields.* With an introduction into Modern Relativistic Quantum Mechanics, Springer-Verlag, Berlin; Heidelberg; New York; Tokyo, 1985, pp. 594 (Texts and Monographs in Physics/Eds. W. Beiglböck, J. L. Birman, E. H. Lieb, T. Regge, and W. Thirring).

The book is devoted to the study of the change in the ground state (called vacuum) of the e^+e^- field in a strong external electromagnetic field. The principal aim is the presentation and development of the theory of pair creation, one of whose particles is bound by the potential of the field, and the other recedes to infinity. Without taking into account the particles that have receded to infinity the ground state in the presence of a deep potential well contains particles in bound states (a so-called charged vacuum).

The book also gives an excellent overview of the experimental work on pair creation in collisions of heavy nuclei. There is no doubt that the tremendous experimental effort directed on the investigation of this process not only will confirm the theory but will also lead to new possibilities of investigating the details of the internuclear potential of heavy nuclei and the mechanisms of dissipation of energy in collisions.

The effective nonperturbative methods and ideas that have arisen in this field are utilized and will be utilized in more complicated theories (Yang-Mills and gravitational fields). The excellent presentation of these questions in the book is very valuable. Many of the problems discussed in the book are at the cutting edge of research. The development of the theory proceeds by a fairly natural extrapolation of the case of weak fields where each state refers either to a particle or to an antiparticle. It is probable that not all the extrapolations will turn out to be correct and the well-prepared reader will find places deserving critical analysis and independent investigation. The authors note also such delicate points as the impossibility of uniquely defining the state of an electron in a super critical atom when this state is immersed into the lower continuum of solutions of the Dirac equation. Such problems deserve further study.

The book gives a review of the important cases of pair creation by fields. A constant electromagnetic field and fields which are switched off as $t \to \pm\infty$ are examined. In this section there are palpable lacunae in the descriptions of the results. Of two equivalent theories—the second-quantized theory and Feynman's theory—essentially only the first one is examined. Moreover, the authors to a great extent utilize Dirac's hole theory. This circumstance makes the reading of the article somewhat more difficult in those cases when the Feynman treatment could have been significantly simpler. The definition of the electron propagator as the vacuum average of corresponding T-ordered field operators leads to several possible Feynman propagators when the definition of the vacuum state is not unique (pp. 234–236). The meaning of this nonuniqueness is not in fact explained. At the same time it is natural to consider that the Feynman propagator is unique and can be defined independently of the vacuum state. One might think that it is defined by the addition of an infinitesimal negative imaginary part to the mass in the proper-time representation or in the E_p representation of Ritus, i.e., in the same manner as in the case of the well-studied configurations of external fields (cf. the collections of articles "Quantum Electrodynamics of Phenomena in an Intense Field" [Proc. (Tr.) P. N. Lebedev Phys. Inst. Acad. Sci. USSR v. 111, 1979] and "Problems of Quantum Electrodynamics of an Intense Field" [Proc. (Tr.) P. N. Lebedev Phys. Inst. Acad. Sci. USSR v. 168, 1986].

The book has not a bad introduction to relativistic quantum mechanics with instructive model examples illustrating the more complex problems discussed later. The authors have expended considerable effort to make the book accessible for beginnning researchers, although not all the problems have been expounded equally successfully. Thus the Klein paradox is discussed in several places but the physical picture still remains in the shadow. Moreover, on p. 120 (cf. also p. 17) an interpretation is given which contradicts the Pauli principle: "Consequently, electrons incident on the barrier from the left can knock out electrons from the filled lower continuum of states situated to the right. This circumstance explains why the reflected electron current is greater than the incident one." Here no statement is made that there exists a second solution with the reflected flux smaller than the incident one. It is characterized by the fact that the positrons in the right hand semispace now move away from the barrier and not towards it as in the first solution. Why then in interpreting pair creation by a field should one not prefer this solution? The main point is that the same solution describes pair creation by a barrier if in the initial state no electron is present, and its scattering if it had been present there. In the latter case the probability of scattering is equal to unity and no pair creation occurs in this state since one more electron of the pair in this state is impossible. In the former case more than one particle also cannot arise in one state, and this is not evident from the formula (10.183). In order to see this (and to reestablish the dimensionality in the cited formula) one should introduce the total observation time T and to work with solutions normalized in such a way that during the time T one particle is incident on the barrier. This time determines also the accuracy $\Delta E = 2\pi/T$ with which states with a given energy E or the distances between energy levels are distinguishable. Then the probability assumes the form

$$N = \int \frac{w}{1+w} \frac{T\,dE}{2\pi} = \sum_E \frac{w}{1+w},$$

where w is the modulus of the ratio of the current of emerging positrons to the current of the incident electrons. We regard the spin state as fixed. From this it can be seen that the probability of observing a particle on a single level is equal to $w/(1+w)$, i.e., less than unity.

By the way we note that the considerable evolution in the understanding of information contained in the so-called one-particle solutions of the Dirac and Klein-Gordon equations has not been reflected in the book; cf., in this regard the aforementioned publications of the Lebedev Institute and the monograph by A. A. Grib, S. G. Mamaev, and V. M. Mostepanenko "Quantum effects in intense external fields" (Atomizdat, M., 1980).

Of great interest are the chapters devoted to the evolution of vacuum in supercritical potentials, to the dynamics of collisions of heavy ions, to polarization of many bodies in intense fields, to bosons, to Yang-Mills fields, to strong fields in the general theory of relativity and other chapters. This rapid enumeration already shows what tremendous material is encompassed in the book. It should be noted that the list of references exceeds 12 pages. Here there is no possibility to dwell on minor defects of the book [for example, the interpretation of formula (19.32)]. Moreover, many of the defects can turn out to be advantages for a better prepared reader since they stimulate reflection and research. On the whole the book is a fundamental effort which contains many original results of the actively working authors. The presentation, as a rule, is clear and accessible even for students. Much useful material for themselves will also be found by specialists in quantum electrodynamics, nuclear theory and adjacent fields.

Scanning electron microscopy

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L. Reimer. *Scanning Electron Microscopy: Physics of Image Formation and Microanalysis.* Springer-Verlag, Berlin; Heidelberg; New York; Tokyo, 1985, pp. 457 (Springer Series in Optical Sciences. V. 45).

The book examines the physical bases of the methods of scanning electron microscopy and x-ray microanalysis which refer to electron-probe methods of studying near-surface layers of solids. Its contents are based on the materials of a lecture course given by the author in the university of the city of Münster (FRG), and also encompass the material of the previously published book: L. Reimer and G. Pfefferkorn, RasterElektronenmikroskopie, 2. Aufl., Springer-Verlag, Berlin; Heidelberg; New York; Tokyo, 1977.

Being designed as a reference textbook the book under review, in contrast to many monographs on the same subject, is characterized by a clear consistency and conciseness of presentation and also by the emphasis in the text on the theoretical aspects of the problems being discussed.

The brief introduction of Ch. 1 introduce the reader to the principle of operation of a scanning electron microscope (SEM) and the physical effects which determine the regimes of its operation. Ch. 2 contains the basic information on the electron optics of an SEM which forms the probe. It also includes a section which describes the principles of scanning and of blanking the latter.

Chapter 3 examines the basic propositions of the theory of the interaction of accelerated electrons with solids. It deals with a phenomena of elastic and inelastic scattering of electrons and their diffusion. The chapter ends with a section describing the effects of local heating, electrical charge and contamination of objects by the electron probe.

Chapter 4 describes the basic regularities in emission of secondary electrons, including Auger-electrons, and x-rays.

Chapters 5–7 are devoted to the technique of detecting different kinds of secondary radiation, and to a description of the methods of processing video signals, and also to the special features of forming the contrast of images within the traditional regimes of operation of an SEM. In Ch. 7 in addition to methods of the induced current and microcathodoluminescence a description is given of the special regimes of operation of an SEM (transmission, electron mirror, thermal wave and some others).

Chapter 8 emphasizes methods of analyzing the crystal structure of solids based on the phenomenon of electron channeling, and also of electron and x-ray diffraction.

The concluding Ch. 9 introduces the reader to the fundamentals of qualitative and quantitative x-ray microanalysis of the element composition of solids in massive and thin-film objects.

The book under review is doubtlessly useful for students and graduate students learning about the physical bases of local methods of analysis of surfaces and, naturally, for specialists working in different fields of scanning electron microscopy. It contains an extensive bibliography and has excellent illustrations (247 figures). At the same time one cannot acknowledge it to be useful that the author in following a formal classification has placed a portion of the material referring to x-ray analysis in other sections of the book. Thus, for example, the problems of the technique of recording and spectroscopy of x-ray and optical radiations have turned out to be included in the same single section of Ch. 5, although, in view of their specific properties they have very little in common.

In conclusion it should be added that the material of well-known monographs in this field becomes rapidly obsolete due to its rapid development, and therefore the appearance of the book under review is very timely, and the newest methods of scanning electron microscopy have been included in it.

Translated by G. M. Volkoff