Preface

In the undergraduate program of Electricity and Magnetism emphasis is given to the introduction of fundamental laws and to their applications. Many interesting and intriguing subjects can be presented only shortly or are postponed to graduate courses on Electrodynamics. In the last years I examined some of these topics as supplementary material for the course on Electromagnetism for the M.Sc. students in Physics at the University Sapienza in Roma and for a series of special lectures. This small book collects the notes from these lectures.

The aim is to offer to the readers some interesting study cases useful for a deeper understanding of the Electrodynamics and also to present some classical methods to solve difficult problems. Furthermore, two chapters are devoted to the Electrodynamics in relativistic form needed to understand the link between the electric and magnetic fields. In the two final chapters two relevant experimental issues are examined. This introduces the readers to the experimental work to confirm a law or a theory. References of classical books on Electricity and Magnetism are provided so that the students get familiar with books that they will meet in further studies. In some chapters the worked out problems extend the text material.

Chapter 1 is a fast survey of the topics usually taught in the course of Electromagnetism. It can be useful as a reference while reading this book and it also gives the opportunity to focus on some concepts as the electromagnetic potential and the gauge transformations.

The expansion in terms of multipoles for the potential of a system of charges is examined in Chap. 2. Problems with solutions are proposed.

Chapter 3 introduces the elegant method of image charges in vacuum. In Chap. 4 the method is extended to problems with dielectrics. This last argument is rarely presented in textbooks. In both chapters examples are examined and many problems with solutions are proposed.

Analytic complex functions can be used to find the solutions for the electric field in two-dimensional problems. After a general introduction of the method, Chap. 5 discusses some examples. In the Appendix to the chapter the solutions for
two-dimensional problems are derived by solving the Laplace equation with boundary conditions.

Chapter 6 aims at introducing the relativistic transformations of the electric and magnetic fields by analysing the force on a point charge moving parallel to an infinite wire carrying a current. The equations of motion are formally the same in the laboratory and in the rest frame of the charge but the forces acting on the charge are seen as different in the two frames. This example introduces the transformations of the fields in special relativity.

In Chap. 7 a short historic introduction mentions the difficulties of the classical physics at the end of the 19th century in explaining some phenomena observed in Electrodynamics. The problem of invariance in the Minkowsky spacetime is examined. The formulas of Electrodynamics are written in covariant form. The electromagnetic tensor is introduced and the Maxwell equations in covariant form are given.

Chapter 8 presents a lecture by Feynman on the capacitor at high frequency. The effects produced by iterative corrections due to the induction law and to the displacement current are considered. For very high frequency of the applied voltage, the capacitor becomes a resonant cavity. This is a very interesting example for the students. The students are encouraged to refer to the Feynman lectures for further comments and for other arguments.

The energy and momentum conservation in the presence of an electromagnetic field are considered in Chap. 9. The Poynting’s vector is introduced and some simple applications to the resistor, to the capacitor and to the solenoid are presented. The transfer of energy in an electric circuit in terms of the flux of the Poynting’s vector is also examined. Then the Maxwell stress tensor is introduced. Some problems with solutions complete the chapter.

The Feynman paradox or paradox of the angular momentum is very intriguing. It is very useful to understand the dynamics of the electromagnetic field. Chapter 10 presents the paradox with comments. An original example of a rotating charged system in a damped magnetic field is discussed.

The need to test the dependence on the inverse square of the distance for the Coulomb’s law was evident when the law was stated. The story of these tests is presented in Chap. 11. The most sensitive method, based on the Faraday’s cage, was introduced by Cavendish and was used until the half of last century. After that time the test was interpreted in terms of a test on a non-null mass of the photon. The theory is shortly presented and experiments and limits are reported.

Chapter 12 introduces the problem of the magnetic monopoles. In a paper Dirac showed that the electric charge is quantized if a magnetic monopole exists in the Universe. The Dirac’s relation is derived. The properties of a magnetic monopole crossing the matter are presented. Experiments to search the magnetic monopoles and their results are mentioned.

In the Appendix the general formulas of the differential operators used in Electrodynamics are derived for orthogonal systems of coordinates and the expressions for spherical and cylindrical coordinates are given.
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