APPLICATIONS OF ELECTRODYNAMICS IN THEORETICAL PHYSICS AND ASTROPHYSICS

Applications of Electrodynamics in Theoretical Physics and Astrophysics, V.L. GINZBURG – Gordon and Breach, New York, 1989.

This book has two major themes: firstly, the unified treatment of both classical or quantum mechanical topics from a "quantum mechanical" (with, and without, Planck's constant) viewpoint; and secondly, the unified treatment of matter and the vacuum. These unified treatments have deep implications for many areas of physics only tangentially related to astronomy, which is the book's final aim in application.

The early chapters of this book lead into the final chapters which address the applications in astronomy. It is significant that the author's final aim is the treatment of astronomy, because the practical astronomer has to deal with radiation which has been affected either by the vacuum or matter, but he can only infer the medium from the resultant radiation. Beside the conventional radio and optical wavelength astronomy, which is kept in mind throughout the book, the final chapters address cosmic ray, x-ray and gamma-ray astronomy. The prospects of gamma-ray astronomy are addressed by the author in order to complete the program of an "all-wavelength" astronomy commenced in 1945-6.

The author adopts a Hamiltonian approach to electrodynamics and the book is an examination of all the possible ways that radiation can occur, e.g., in uniformly accelerated charges, relativistic and nonrelativistic moving particles, Cerenkov and Doppler effects, superluminal sources of radiation, transition radiation and transition scattering, reabsorption and transfer of radiation, wave propagation in plasmas, fluctuations and van der Waals forces.

The transition from classical electrodynamics to quantum electrodynamics is treated by the author via the Hamiltonian formalism in a manner similar to the transition from the classical (Newtonian) mechanics to nonrelativistic quantum mechanics. However, what the author does not point out in this transition is that whereas the vector potential and scalar potential fields in modern "western" electrical engineering play an auxiliary role (cf. Barrett, 1990), they play a central role in quantum theory, particularly the scalar potential.

The author's initial introduction utilizes the vector potential $\mathbf{A}$ and the scalar potential, Φ, but they are declared to be "known not to be uniquely defined functions" (p. 2). That may be. However, having chosen a definition of $\mathbf{A}$ and Φ, i.e., having chosen a gauge, then the boundary conditions of the problem are uniquely defined, as the author knows. For example, the author acknowledges (p. 15) that when applying perturbation theory, the results cannot be automatically independent of the gauge chosen for the Hamiltonian. Again, in his use of the Coulomb gauge ($\operatorname{div} \mathbf{A} = 0$) it is pointed out (p. 3) that use of this gauge is equivalent to the presence of only transverse **A** fields, but that use of the Lorentz gauge (changes in an arbitrary **A** function = 0) permit both longitudinal and transverse **A** fields. On the other hand, longitudinal fields can be a function of Φ in the Coulomb gauge. Changes in this gauge field are also instantaneous as $\Phi = e/r_{12}(t)$, and changes in e_1 occur simultaneously with e_2.

This book addresses a number of concepts which are not covered systematically elsewhere, but are scattered throughout the book. Some of these concepts are:

Concept #1: *Transverse and longitudinal E.M. Fields.* The total energy of the field is the sum of energies of the transverse and longitudinal fields (p. 5). The energy of the longitudinal field is the energy of the Coulomb interaction between charges, and essentially unquantizable. $\mathbf{A}(r, t)$ is treated as if the e.m. field is confined to a "large box" (cavity?) and the derivation of pseudophotons or photons with zero momentum from standing waves, is in a way reminiscent of Jennison's (1978, 1979) approach to describing the electron. "Conventional" photons are also obtained by the author from the vector potential written as a sum of traveling waves.

With the vector potential playing such a crucial pivotal role in this "eastern", i.e., Soviet book, one may wonder how it came about that in the "west" the **A** field was banished from playing a central role in Maxwell's theory and relegated to being a mathematical (but not physical) auxiliary. This banishment we know was not due to Maxwell nor to Faraday. In fact, for both Maxwell and Faraday the **A** field was central (cf, Bork, 1967a,b; Hunt, 1984; Nahin, 1987). "Maxwell's Theory" and "Maxwell's equations" are really the interpretation of Maxwell by the Maxwellians (Hunt, 1984) – chiefly, Heaviside, Fitzgerald, Lodge and, perhaps, Hertz. It was Heaviside who "murdered the **A** field" and whose work influenced the pivotal discussion at the 1888 Bath meeting of the British Association. The "Maxwell equations" of today are due to Heaviside's "redressing" of Maxwell's work, and should, more accurately be known as the "Maxwell-Heaviside equations". Essentially, Heaviside took the twenty equations of Maxwell and reduced them to the four, known now as "Maxwell's equations".

For Maxwell, the heart of his truly *dynamic* theory of electromagnetism was Faraday's concept of *the electrotonic* state of the ether, which was the origin of the vector potential. The Maxwell-Faraday theory concerned stresses and strains in the ether, and also propagation in the ether. Heaviside, Fitzgerald and Lodge banished scalar and vector potentials from the propagation equations, but the center of concern was still the *dynamic of the ether.* Heaviside's comment that the electrostatic potential was a "physical inanity" was probably correct for the 19th century, but the potential regained its sanity in the 20th starting with the work of Weyl. Both Heaviside and Poynting agreed that the functions of wires is to serve as sinks into which energy passed from the ether and was convected into heat. Wires conduct electricity with the Poynting vector pointing at right angles to the wire. Modern theory is not straightforward about where this energy goes but nevertheless retains Poynting's theorem. The energy flows not *through* a current carrying wire itself but through the ether around it – or through whatever energy storing substance a modern theorist imagines exists in the absence of the ether. Heaviside was probably correct to banish scalar and vector potentials from propagation equations due to the resulting instantaneous propagation in certain (but not all) gauges, as well as due to the fact that the notion of gauge (Maßstabinvarianz) was not yet invented and thus not known to the Maxwellians. However, these fields remained as a repository of energy and the redressed Maxwell theory of the Maxwellians remained a *true dynamic* theory of electromagnetism.

But all dynamics were banished by Hertz. Hertz banished even the stresses and strains of the ether and was vigorously opposed in this by the Maxwellians: Heaviside, Fitzgerald and Lodge (see Hunt, 1984). Nonetheless, the Hertz orientation finally prevailed, and present day "Maxwell's theory" is a system of equations for electrodynamics *which has lost its dynamical basis.*

One might, therefore, interprete the author's book as a return to a more *dynamic* conception of electrodynamics, and the Maxwellians might even approve, given the explicit use of dynamics based on gauge choice. For example, the field of a uniformly moving charge is the sum of the transverse and longitudinal components with respect to the propagation direction vector $\mathbf{k}$ (pp. 174, 192); and for a charge at rest the longitudinal component is the main field. Longitudinal or electrostatic waves do not propagate in an isotropic plasma, but do propagate with phase velocity c/n^3 and group velocity $d\omega/dk$ in a medium with spatial dispersion (p. 283). Longitudinal waves also propagate in nonlinear media.

The 19th century battle between Heaviside and Tait concerning the use of quaternions, culminating in victory for Heaviside and vector analysis, may also be reinterpeted. *Without* the concepts of gauge, global, (as opposed to local), fields, nonintegrable phase factors (Wu and Yang, 1975) and topological connections, quaternions and the vector and scalar potential fields were getting in the way of progress. That is not to say that either quaternionic algebra or the potentials were, or are, unphysical or unimportant. It is to say, rather, that the potentials could not be understood then with the theory and the mathematical tools available. Certainly it is *now* realized that the algebraic formulation of electromagnetism is more complicated than even quaternionic algebra, and certainly more complicated than simple vector analysis (see Chisholm and Common, 1986). Therefore, by placing of the potential in center stage, this book treats electrodynamics as a *dynamic* theory again.

Concept #2. *Zero Point Energy.* For the author, zero point energy (the lowest energy of the harmonic oscillator) is a "reflection of the profound difference between classical and quantum theories" (p. 14). This confinement puts the author at odds with those who attribute zero point energies to classical fields as well as quantum fields (e.g., Cercignani et al, 1972). However, even if the author confines zero point energy to quantum fields, for the author they can occur for any fields, whether acoustical, gravitational, or hadronic. The author denies that spontaneous radiation is due to zero point energy fluctuations – such radiation existing even for classical systems (p. 20).

Concept #3. *Radiation from a uniformly moving electron.* The author asks the question whether a uniformly moving electron can emit radiation? The answers are: yes, if the electron is moving uniformly in a non-inertial frame; yes, if moving uniformly in a medium, e.g., Cerenkov and transition radiation; but no, if moving in a vacuum in an inertial frame of reference with constant velocity $v < c$. That is, for the author the *local conditions,* not the observer's location (i.e., *not the nonlocal or special relativity condition*), determines the result.

Concept #4. *The distinction between the total energy flux, the variation of the field energy and the work done by the radiation force.* For the author the radiative force can vanish during uniformly accelerated motion of a charge even in the presence of radiation – due to the presence of a total energy flux, which would be equal, in such a case, to the variation of the field energy.

Concept #5. *The Vacuum as a Birefringent (Anisotropic) Medium.* A reciprocity between charge activity in a vacuum and in a medium is described by the author. For example, for a given motion, a charge either can emit radiation in a vacuum but not a medium, or, for a uniformly moving charge, can emit radiation in a medium but not a vacuum (p. 93). The author also shows that the equations of the e.m. field can become nonlinear and that the vacuum behaves like a birefringent medium under a strong e.m. field (p. 116). Whether or not a magnetic field is strong enough to lead to nonlinear effects is determined by its ratio to the *characteristic field* (4.4×10^{13} G) (p. 116). In essence, *the vacuum behaves as a medium* in the nonlinear approximation, so a uniformly moving charge in a sufficiently strong external field could emit radiation even in a vacuum (Cerenkov and transition radiation) (p. 121). Faraday, Maxwell and the Maxwellians (Heaviside, Fitzgerald and Lodge) thought of energy as being stored in a stressed or strained state of the ether. *With the rejection of the ether, the field became, and remains, a greater mystery now than it was to the Victorians!* A conception of the vacuum as a dynamic entity, however, permits a return to the Maxwellian position of electromagnetism as a *dynamic* phenomenon.

Concept #6. *"Photons in the Medium".* With a vector potential expansion of the free field in a medium, the author is able to treat energy propagation in the medium in a manner similar to that of energy propagation in the vacuum. Therefore solid state propagating entities are called "photons in the medium" (p. 99). Plasmons (plasma longitudinal waves), for example, are described as a special case of "photons in the medium" (p. 128). Furthermore, the difference between plasmons and quanta of the e.m. field in a medium is described as simply the difference between longitudinal and transverse waves (p. 138) According to the authors treatment, polaritons are classically equivalent to normal e.m. waves propagating in a solid, and in quantum terminology polaritons are "photons in the medium" (p. 263).

Concept #7. *"Quantum" Approach to even Classical Problems.* The author applies quantum concepts to emission, absorption and amplification of e.m. waves during the motion of charges or various "systems" (atoms, clusters, antennas) in a medium – even for essentially classical problems when the scale used does not depend on Planck's constant (p. 123). Thus, the author does not change his approach when addressing classical problems but merely uses, or does not use, the Planck constant "scaling" depending on the scale of the phenomena addressed, and quantum mechanical transitions are related to parametric excitation.

Concept #8. *Magnetic Monopole and Magnetic Charge.* With the caveat that no magnetic monopoles have been discovered, the author explores the concept of magnetic monopole and charge not according to the relatively heavy (10^{-8} g) monopoles required by grand unification theorists, but rather within the framework of classical electrodynamics. The author also examines a "true" magnetic dipole, consisting of a dipole formed by two magnetic monopoles (or magnetic charges) of opposite sign. Examining the symmetrized form of Maxwell's theory which involves using "magnetic charge" has long been instructive and useful. In his "duplex" form of Maxell's equations, Heaviside wrote $\mathbf{M} = -\nabla\times\mathbf{E}$ as well as $\mathbf{J} = \nabla\times\mathbf{H}$, where $\mathbf{J}$ and $\mathbf{M}$ are two vector current densities (Nahin, pp. 109-110). $\mathbf{M}$ is related to m_c, the flow of *free* magnetic particles. At the end of each analysis, Heaviside set $m_c = 0$. The endeavor is very similar to one described recently (Harmuth, 1986a-c; Barrett, 1988, 1989a-b) which has caused much *Sturm und Drang* to the current believers in the inviolability of "Maxwell's theory" (that is, of course, not the original Maxwell theory, but that theory as modified or "redressed" by the Maxwellians – the major figure of this group being, of course, Heaviside himself!).

Concept #9. *Concept of Toroidal Moment.* A torus-shaped solenoid (or toroid) carrying a current, but with winding such that no azimuthal current is carried (e.g., two windings with currents flowing in the same direction), has no magnetic nor electic moment, and there is only a magnetic (azimuthal) field inside the toroid. Such a system has only a toroidal dipole (or higher) moment (p. 150). The author shows that if a toroidal dipole moves in a vacuum with constant velocity then the electric and magnetic fields are zero outside the toroid but there is both an electric and a magnetic field inside.

Concept #10. *Concept of Superluminal Velocities.* As is well known, the phase velocity of light can be greater than c, and the group velocity can be greater than c in the case of anomalous dispersion. The author also considers a number of examples in which the "apparent" velocity of light spots (or the expansion of signal envelope in a direction perpendicular to the line of vision) (p. 201) and the speed of travel of a spot from a distant rotating light source across a screen, are also faster than c. However, as none of these examples of traveling spots can be used for transferring signals with velocities $v > c$, the highest velocity for transferring perturbations, interactions and signals still remains c.

Concept #11. *Quantum Mechanical Description of Fluctuations in an Electric Circuit.* The author demonstrates the physical meaning of the fluctuation-dissipation theorem by a treatment based on the electrical circuit. This treatment is completely general and provides physical insight into fluctuation phenomena. Such flutucation phenomena are related to van der Waals forces.

In conclusion, *Applications of Electrodynamics in Theoretical Physics and Astrophysics* provides a fresh dynamic approach to a number of important topics in electromagnetism. One goal of the author is to provide the background for understanding from the astronomer's point of view how radiation received from a distant source *could have* come about. Unlike the laboratory experimenter, who controls the situation, the astronomer must deliberate like a detective only on the received results. Another goal of the author is always to gain deep physical insight. The physical model underpinning e.m. phenomena at the core of the author's treatment is, I believe, similar to that of the very early expositors, Faraday, Maxwell and the Maxwellians, and also of the very recent expositors, e.g., Wu and Yang, but is refreshingly different from that of many inbetween. Because of this, and the book's coverage of very modern and future themes, it is recommended to any reader, whether astronomer or not.

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