

Electrodynamics of Moving Media

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On the basis of the Minkowski formulation, the total energy-momentum tensor of a system consisting of matter and electromagnetic fields is derived from the macroscopic theory. The analysis of this tensor shows that the electromagnetic fields supply the matter with momentum and energy. Consequently, the electromagnetic part and the material part overlap each other in the total energy-momentum tensor. Hence it is impossible to divide the total energy-momentum tensor into an electromagnetic tensor and a material tensor.

In a closed system, in general, only the total energy-momentum tensor has physical significance and can be defined.

Further, the generalized force which acts on the matter is obtained and interpreted clearly.

I. Introduction

Electrodynamics of moving media has been discussed by a large number of investigators for long years, and until the present many different forms of an electromagnetic energy-momentum tensor within media have been put forward^{1–4}. However, no form is universally accepted, although Minkowski's tensor is the most well-known and widely used of them⁵.

The present paper develops Møller's theory of an elastic body⁶ and analyzes, on the basis of the Minkowski formulation, a system consisting of matter and electromagnetic fields. The effect of the electromagnetic fields on the matter is revealed. Further, the generalized force which acts on the matter is obtained and interpreted clearly.

For the sake of simplicity, only isotropic and nondispersive media with linear constitutive relations are considered. Further, the summation convention is used. The Latin subscripts assume the values 1, 2, 3, 4, whereas the Greek subscripts assume the values 1, 2, 3.

II. The Lorentz Force, the Joule Heat, and the Electrostriction and Magnetostriction Forces

In the first place, the force per unit volume that acts on stationary media in stationary electromagnetic fields is considered. If the elastic force is left out of consideration, it is given by^{7, 8}

$$\mathbf{f}_{\text{ext}} = \rho \mathbf{E} + \mathbf{J} \times \mathbf{B} - \frac{1}{2} E^2 \text{grad } \epsilon - \frac{1}{2} H^2 \text{grad } \mu + \text{div } \mathbf{T}, \quad (1)$$

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where ρ and \mathbf{J} are the true charge and current densities. The last term in (1) is the vector whose components are

$$(\text{div } \mathbf{T})_\alpha = \partial \sigma_{\alpha\beta} / \partial x_\beta, \quad (2)$$

where

$$\sigma_{\alpha\beta} = -\frac{1}{2} \alpha_1 E_\alpha E_\beta - \frac{1}{2} \alpha_2 E^2 \delta_{\alpha\beta} - \frac{1}{2} b_1 H_\alpha H_\beta - \frac{1}{2} b_2 H^2 \delta_{\alpha\beta}; \quad (3)$$

the Kronecker symbol is denoted by $\delta_{\alpha\beta}$. The coefficients α_1 and α_2 in (3) represent the rate of change due to the strains of the permittivity ϵ of the medium, whereas b_1 and b_2 represent that of the permeability μ .

Note that the last term in (1) is quite different from the other terms in nature. It represents the electrostriction and magnetostriction forces; these act as surface forces, because $\sigma_{\alpha\beta}$ represents the internal stresses which occur to evoke the strains. In contrast with it, the first four terms in (1) represent the Lorentz force, which acts as a volume force.

Even in the general case of time-dependent fields, only the Lorentz force and the electrostriction and magnetostriction forces act immediately on the medium. Moreover if the fields do not vary rapidly, it may be assumed that the Lorentz force and the electrostriction and magnetostriction forces are represented by (1). The generalized force is discussed in detail in Section VI.

Next the case in which media are moving with a constant velocity \mathbf{v} is considered. The following identity is generated from Minkowski's field equations by the tensor manipulation⁹:

$$f_i^* = -\partial S_{ik} / \partial x_k, \quad (4)$$

where

$$f_i^* = F_{ij} J_j + \frac{1}{4} \left(F_{kl} \frac{\partial H_{kl}}{\partial x_i} - \frac{\partial F_{kl}}{\partial x_i} H_{kl} \right), \quad (5)$$

Electrodynamics Of Moving Media

RUDOLPH MORTON KALAFUS



Electrodynamics Of Moving Media:

Electrodynamics of Moving Media National Research Council (U.S.). Committee on electrodynamics of moving media, William Francis Gray Swann, John Torrence Tate, Harry Bateman, 1922 *Models of Particles and Moving Media* Donald Dunn, 2012-12-02 *Models of Particles and Moving Media* deals with the use of mathematical models to study electrical interactions with moving particles and moving media Topics covered range from space time and the Galilean transformation to the Lorentz transformation of time and space and of Maxwell's equations Forces and wave interaction with uniformly moving circuits and continua are also considered along with non uniform motion of charged particles in prescribed electric and magnetic fields Comprised of seven chapters this book begins with an overview of some of the ways in which motion can be described with particular reference to the concept of space time and the Galilean transformation The discussion then turns to the Lorentz transformation of time and space giving emphasis on the transformation of coordinates time dilation and the Lorentz contraction and conservation of mass and energy After an analysis of the Lorentz transformation of Maxwell's equations forces and wave interaction with uniformly moving circuits and continua are reviewed along with non uniform motion of charged particles in prescribed electric and magnetic fields The book concludes by describing the use of the Lagrangian model and the Eulerian model to determine the motion of many interacting particles and the motion of charged and conducting fluids respectively This monograph is written primarily for students and researchers in the fields of mathematics and physics

ELECTROMAGNETISM IN MOVING, CONDUCTING MEDIA. RUDOLPH MORTON KALAFUS, 1966 *Electrodynamics of Moving Media* National Research Council (U.S.). Committee on electrodynamics of moving media, William Francis Gray Swann, John Torrence Tate, Harry Bateman, 1922 **Electrodynamics of Moving Media** Luiz Valente Boffi, 1957

Electrodynamics of Solids and Microwave Superconductivity Shu-Ang Zhou, 1999-07-23 Die Elektrodynamik von Festkörpern ist ein interdisziplinär angelegtes Thema zu dem elektromagnetische Phänomene mechanische Bewegungen und Verformungen sowie Wärmeleitungen in festen Stoffen gleichermaßen beitragen Dieses einführende und dennoch umfassende Lehrbuch zur Theorie der Elektrodynamik und Halbleitertechnik richtet sich an Physiker ebenso wie an Elektrotechniker Maschinenbauer und Studenten der einschlägigen Fachrichtungen 08 99

Electrodynamics Masud Chaichian, Ioan Merches, Daniel Radu, Anca Tureanu, 2016-10-31 This book is devoted to the fundamentals of classical electrodynamics one of the most beautiful and productive theories in physics A general survey on the applicability of physical theories shows that only few theories can be compared to electrodynamics Essentially all electric and electronic devices used around the world are based on the theory of electromagnetism It was Maxwell who created for the first time a unified description of the electric and magnetic phenomena in his electromagnetic field theory Remarkably Maxwell's theory contained in itself also the relativistic invariance of the special relativity a fact which was discovered only a few decades later The present book is an outcome of the authors teaching experience over many years in different countries

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New Advances in Maxwell's Equations and Applications Er-Ping Li, Zhong Lin Wang, 2025-02-01 This book offers a comprehensive examination of ongoing advancements in theoretical and experimental approaches to Maxwell's equations It focuses on three key aspects quantum effects scale effects and kinetic effects which exert subtle influences at microscopic levels Addressing pressing challenges for future progress the text explores the interplay of these phenomena within classical electromagnetism The evolution of data communication and information technology has led to a demand for high density minimization ultra compact nano photo electronic integration As electronic devices scale down to nanometer and sub nanometer levels classical Maxwell's equations reveal quantum effects This book provides insights into these advancements focusing on potential applications in nano scale electronic and optic devices Tailored for physicists engineering scientists electronics engineers and developers this text serves as a valuable resource It guides readers from classical Maxwell's equations to their quantum affected counterparts providing essential insights for electromagnetic simulation and the design of nano scale electronic and optic systems With its blend of theoretical foundations and practical applications this book equips professionals with the knowledge needed to apply these advancements in real world scenarios

Non-Stationary Electromagnetics Alexander Nerukh, Trevor Benson, 2018-10-26 This book is devoted to the investigations of non stationary electromagnetic processes The investigations are undertaken analytically mainly using the Volterra integral equations approach The book contains a systematic statement of this approach for the investigations of electrodynamics phenomena in the time domain and new results and applications in microwave techniques and photonics Particular consideration is given to electromagnetic transients in time varying media and their potential applications The approach is formulated and electromagnetic phenomena are investigated in detail for a hollow metal waveguide which contains moving dielectric or plasma bounded medium and dielectric waveguides with time varying medium inside a core

Nuclear Science Abstracts, 1975-03 *Personal Knowledge* Michael Polanyi, 2012-09-21 In this work the distinguished physical chemist and philosopher Michael Polanyi demonstrates that the scientist's personal participation in his knowledge in both its discovery and its validation is an indispensable part of science itself Even in the

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