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Review

Generalized Lorenz–Mie theories, the third decade: A perspective

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ABSTRACT

During the year 2008, we have been commemorating, in several places, the hundredth anniversary of the famous 1908-paper by Mie describing the interaction between an electromagnetic plane wave and a homogeneous sphere defined by its diameter d and its complex refractive index m. Due to the existence of a prior version by Lorenz, Mie's theory may also be named as Lorenz–Mie theory (LMT). The generalized Lorenz–Mie theory (GLMT) *stricto sensu* deals with the more general case when the illuminating wave is an arbitrary shaped beam (say: a laser beam) still interacting with a homogeneous sphere defined by its diameter d and its complex refractive index m. The name "GLMTs" is generically used to designate various variants for other particle shapes when the method of separation of variables is used. The present paper provides a review of the work accomplished in this generalized field during the last decade (the third decade). As a convenient selection criterion, only papers citing the work of the group of Rouen have been essentially used, with ISIweb of knowledge providing a database.

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Contents

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1. Introduction

During the year 2008, a famous paper by Gustav Mie, dated 1908 [1,2] has been commemorated in several places (GAeF conference 2008 on "Light Scattering: Mie and More-commemorating 100 years Mie's 1908 publication", 3rd–4th July, Karlsruhe, Germany [3]; International Radiation Symposium IRS 2008, 3rd–8th August, Foz do Iguaçu, Brazil [4]; 11th Conference on Electromagnetic and Light Scattering, 7th–12th September 2008, Hatfield, UK [5]; Mie theory 1908–2008, Present Developments and Interdisciplinary Aspects of Light Scattering, 15th–17th September, Universität Halle-Wittenberg). Mie's paper describes the interaction between an electromagnetic plane wave and a homogeneous sphere defined by its diameter d and its complex refractive index m, in the framework of the macroscopic version of Maxwell's electromagnetism, relying on a method of separation of variables in spherical coordinates. However, there has been a prior version due to Lorenz [6,7] which is empirically equivalent to the one of Mie, although it is not based on the macroscopic version of Maxwell's electromagnetism, but on a mechanical theory of aether [8–11]. As a result, I preferred to refer to Mie's theory as to Lorenz–Mie theory (LMT). However, the strangeness of having such two empirically equivalent versions, one relying on Maxwell's equations and the other on an aether mechanical version, is something which needed to be clarified. In a presentation in Halle-Wittenberg, I discussed the issue in the framework of a non-demonstrated philosophical theorem (!) called Duhem–Quine theorem, telling us that theories are under-determined by experiments. A paper on this issue is under preparation.

Regarding generalized Lorenz–Mie theories (GLMTs), things started as follows. I had to measure velocities in a high-frequency argon–helium plasma jet, seeded with alumina particles, by using laser-Doppler velocimetry (LDV) [12–14]. Due to the high temperatures involved (typically 5000 K for atoms), it would have been useful to possess simultaneous measurements of sizes and velocities to check that the embedded particles, big enough for not experiencing complete vaporization in the plasma, were small enough for not drifting behind the plasma. I have been able to check this requirement in an indirect way, but not in a direct way, due to the lack of adequate measurement techniques available at that time. More generally, the problem to know how to measure simultaneously velocities and sizes of particles transported in flows was raised, by the end of the seventies, in many places and in many fields, for instance for plasma spraying or for the study of sprays in combustion. Various papers discussing various laser techniques were published, e.g. [15,16], but the examination of the literature exhibited the existence of a basic flaw, that no satisfactory light scattering theory to deal with laser techniques was available. Indeed, laser beams are transversely confined and, under common circumstances, if the size of the scatterer is larger than the transverse dimensions of the illuminating beam, then we must expect that LMT is misleading. A GLMT was required.

In 1978 or so, soon after my State Thesis was defended, the first equations for the construction of a GLMT have been written. The first paper, in which precursors are acknowledged, has been published in 1982 [17]. It considered the case of a homogeneous sphere defined by (d, m) illuminated on-axis by what has been called a circularly symmetric beam, such as a Gaussian laser beam. This was actually a special case but its study revealed specific numerical difficulties due to too time-consuming computations concerning beam shape coefficients summarizing the description of the illuminating beam. The subsequent years have been essentially devoted to these aspects of the theory (and also to a deepening of its understanding), up to the introduction of what has been called the localized approximation, at least for the on-axis case [18–24]. The expression "localized approximation" may actually be viewed as an unfortunate misnomer because it has been later realized that it provided a localized beam model exactly satisfying Maxwell's equations [25,26], although there is indeed a sense in which it is an approximation.

In 1988, we were ready to publish the general version of the GLMT in what I consider as the "pivot paper" dealing with the case of a homogeneous sphere arbitrarily located in an arbitrary shaped beam [27]. Due to the emphasis given in this paper to the case of Gaussian beams, it has sometimes been believed that GLMT was restricted to such beams. This is, however, not the case. GLMT is genuinely an arbitrary beam theory (ABT) as may be more obvious from [28]. The expression ABT is also possibly used in reference to another version, equivalent to GLMT, published by Barton et al. [29]. More work has afterward been necessary before the possibility of extensive applications, such as to the design and understanding of measuring techniques, in particular concerning the elaboration of a localized approximation valid for the "pivot paper" version [30,31]. Such applications to measuring techniques were provided for the study of the trajectory ambiguity effect in phase-Doppler anemometry, devoted to the simultaneous measurements of velocities and sizes of individual spherical particles in flows [32,33]. As a whole, more than 10 years have been used to properly build the theory and another five years to reach a genuine application (in the field of optical particle characterization, the original motivation).

An overall exposition of GLMT can be found in a manuscript which has been available since 1996 [34], and an associated book is under preparation. Several review papers on GLMT (or GLMTs) have furthermore been published. The first one, in 1991 [35], dealt with about one decade of GLMT. It essentially contains, under a single roof, various aspects of the formalism. A second review paper, in 1994 [36], three years later, could discuss applications of GLMT to phase-Doppler anemometry, more specifically to what has been a troublesome feature of this measurement technique, known as the trajectory ambiguity effect (or defect). A few other applications are also briefly mentioned. Another review paper, the significant last one, dated 2000 [37], could contain the discussion of extensions of the theory (GLMTs for various scatterer shapes) and of applications (phase-Doppler instruments, radiation pressure, imaging, morphology-dependent resonances (MDRs), miscellaneous). The interest and/or the relevance of GLMT(s) to light scattering, and to optical particle characterization is testified by independent reviews such as by Durst [38] or by Jones [39] and in textbooks [40–42].

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