Comment on “Unified treatment of nonlinear optical force in laser trapping of dielectric particles of varying sizes”

Gérard Gouesbet*
Campus Universitaire du Madrillet 76800, CORIA-UMR 6614-Normandie Université CNRS-Université et INSA de Rouen, Saint-Etienne-du Rouvray, France

(Received 21 March 2022; accepted 16 June 2022; published 11 July 2022)

In a comprehensive, important, and innovative paper devoted to the evaluation of nonlinear optical force exerted on particles trapped in optical tweezers, imprecise statements have, however, been made which may be misleading to newcomers. The present Comment aims to correct these statements in order to avoid the propagation of incorrect beliefs.

DOI: 10.1103/PhysRevResearch.4.038001

The first comment devoted to Ref. [1] concerns the status of the generalized Lorenz-Mie theory (GLMT in short) which is a well -known generalization of the classical Lorenz-Mie theory, e.g., Refs. [2–4] and many references therein, which has been, in particular, successful to the evaluation of optical forces since 1985 [5] and 1988 [6,7] with many successful comparisons with experiments, e.g., a review in Ref. [8], and torques [9]. In Ref. [1], GLMT results are opposed to other results obtained from a so-called “exact Mie theory” (EMT in short) dated 2000 [10] restricted to the evaluation of axial optical forces exerted on a transparent sphere by a focused Gaussian beam which is represented by a Richards and Wolf angular spectrum decomposition.

In Ref. [1], the conclusions are drawn based on the results using a localized approximation, implemented in the GLMT framework, which itself may be an inappropriate choice (discussed later). Therefore, based on these results, it would be deeply incorrect to consider GLMT as an ”approximation.” GLMT is indeed an exact, rigorous, and complete generalization of the Lorenz-Mie theory (LMT), which allows one to evaluate not only optical forces and torques, but also scattered fields and internal fields as well, not only for Gaussian beams but also for arbitrary shaped beams. Therefore, in principle, EMT should be exactly equivalent to GLMT as far as the applicability realm of EMT (more restricted than the one of GLMT) is concerned.

In other terms, the authors of Ref. [1] opposed the EMT which is “exact” to a more general theory which is exact as well although the reader may have a false impression of it, as being an approximation based on the results obtained by using a localized approximation (the terminology “localized beam model” which avoids any ambiguity has been used as well, e.g., Refs. [11,12] and references therein). Furthermore, the authors claim that EMT provides better results than GLMT. Actually, in GLMT, the beam is encoded in a double set of coefficients known as beam shape coefficients (BSCs). Lorenz-Mie theory is recovered from GLMT by implementing BSCs relevant to the LMT situation. The fact that GLMT results are found less satisfactory than EMT may then be due to the fact that improper values of the BSCs have been implemented when running the GLMT. The explanation given by the authors that discrepancies “might be due to the fact that EMT incorporates all the surface effects and calculations are performed for tight focusing conditions that are missing in other theories” is incorrect since GLMT is a completely rigorous theory which, once more, should allow to recover the results of EMT when BSCs are properly implemented. For the same reason, the statement according to which “GLMT and EMT differ qualitatively as well as quantitatively” is another misleading statement. Actually, although the GLMT has been implemented in Ref. [1] using a localized approximation to the evaluation of the BSCs, there are other ways to evaluate the BSCs and, most likely, the use of a localized approximation is not appropriate under the circumstances described in the paper. Similarly, the authors have mistakenly made another statement saying that the “GLMT approximation is solved only by using paraxial approximation.” It depends on the way used to evaluate BSCs insofar as GLMT can indeed deal with nonparaxial formulations. It might, furthermore, happen that the agreement between EMT and experiments could be accidental, and that other forces, besides optical forces, could actually act in the experiments, a possibility which might require further investigations.

The second comment concerns a sentence according to which “no general theory has been predicted till now for pulsed excitation.” This is ignoring several published papers on the issue. For a fairly exhaustive bibliography related to the pulse version of GLMT, we may refer to Refs. [13–22]. Many other theoretical studies discussing the scattering by pulses may be obtained from review papers, particularly, [4,23], which may be completed by Refs. [24–27].

*Corresponding author: gouesbet@coria.fr

A. Devi and A. K. De (authors of the commented paper) have been informed of the preparation of this Comment. They have been helpful to polish it in a very cooperative way. It is, therefore, my pleasure to heartily thank them for their open mindedness and their friendly behavior.

[1] A. Devi and A. K. De, Unified treatment of nonlinear force in laser trapping of dielectric particles of varying sizes, Phys. Rev. Res. **3**, 033074 (2021).
[2] G. Gouesbet, G. Gréhan, and B. Maheu, *Combustion Measurements*, edited by N. Chigier (Hemisphere, New-York, 1991), pp. 339–384.
[3] G. Gouesbet and G. Gréhan, *Generalized Lorenz-Mie Theories*, second ed. (Springer, Berlin, 2017).
[4] G. Gouesbet, T-matrix methods for electromagnetic structured beams: A commented reference database for the period 2014-2018, J. Quant. Spectrosc. Radiat. Transfer **230**, 247 (2019).
[5] G. Gouesbet, G. Gréhan, and B. Maheu, Scattering of a Gaussian beam by a Mie scatter center, using a Bromwich formalism, J. Opt.s (Paris), Republished in *Selected Papers on Light Scattering*, edited by M. Kerker, SPIE Milestone Series Vol. 951 (SPIE, Bellingham, WA, 1988), pp. 83–93.
[6] G. Gouesbet, B. Maheu, and G. Gréhan, Light scattering from a sphere arbitrarily located in a Gaussian beam, using a Bromwich formulation, J. Opt. Soc. Am. A **5**, 1427 (1988).
[7] B. Maheu, G. Gouesbet, and G. Gréhan, A concise presentation of the generalized Lorenz-Mie theory for arbitrary location of the scatterer in an arbitrary incident profile, J. Opt. **19**, 59 (1988).
[8] G. Gouesbet, Generalized Lorenz-Mie theories and mechanical effects of laser light, on the occasion of Arthur Ashkin's receipt ot the 2018 Nobel prize in physics for his pioneering work in optical levitation and manipulation: A review, J. Quant. Spectrosc. Radiat. Transfer **225**, 258 (2019).
[9] H. Polaert, G. Gréhan, and G. Gouesbet, Forces and torques exerted on a multilayered spherical particle by a focused Gaussian beam, Opt. Commun. **155**, 169 (1998).
[10] P. A. Maia Neto and H. M. Nussenzveig, Theory of optical tweezers, Europhys. Lett. **50**, 702 (2000).
[11] J. J. Wang and G. Gouesbet, Note on the use of localized beam models for light scattering theories in spherical coordinates, Appl. Opt. **51**, 3832 (2012).
[12] X. Jia, J. Shen, and H. Yu, Calculation of generalized Lorenz-Mie theory based on the localized beam models, J. Quant. Spectrosc. Radiat. Transfer **195**, 44 (2017).
[13] G. Gouesbet and G. Gréhan, Generic formulation of a generalized Lorenz-Mie theory for a particle illuminated by laser pulses, Part. Part. Syst. Charact. **17**, 213 (2000).
[14] L. Méès, G. Gréhan, and G. Gouesbet, Time-resolved scattering diagrams for a sphere illuminated by plane wave and focused short pulses, Opt. Commun. **194**, 59 (2001).
[15] L. Méès, G. Gouesbet, and G. Gréhan, Scattering of laser pulses (plane wave and focused Gaussian beams) by spheres, Appl. Opt. **40**, 2546 (2001).
[16] L. Méès, G. Gouesbet, and G. Gréhan, Interaction between femtosecond pulses and a spherical microcavity: Internal fields, Opt. Commun. **199**, 33 (2001).
[17] M. Brunel, L. Méès, G. Gouesbet, and G. Gréhan, Cerenkov-based radiation from superluminal excitation in microdroplets by ultra-short pulses, Opt. Lett. **26**, 1621 (2001).
[18] G. Gouesbet, L. Méès, and G. Gréhan, *Laser techniques for Fluid Mechanics* (Springer, Berlin, 2002), pp. 371–375.
[19] L. Méès, J. P. Wolf, G. Gouesbet, and G. Gréhan, Two-photon absorption and fluorescence in a spherical micro-cavity illuminated by using two laser pulses: Numerical simulations, Opt. Commun. **208**, 371 (2002).
[20] L. Méès, G. Gouesbet, and G. Gréhan, Numerical predictions of microcavity internal fields created by femtosecond pulses, with emphasis on whispering gallery modes, J. Opt. A: Pure Appl. Opt. **4**, S150 (2002).
[21] Y. P. Han, L. Méès, K. F. Ren, G. Gréhan, Z. S. Wu, and G. Gouesbet, Far scattered field from a spheroid under a femtosecond pulsed illumination in a generalized Lorenz-Mie theory framework, Opt. Commun. **231**, 71 (2004).
[22] L. Méès, G. Gouesbet, and G. Gréhan, Transient internal and scattered fields from a multi-layered sphere illuminated by a pulsed laser, Opt. Commun. **282**, 4189 (2009).
[23] G. Gouesbet, Latest achievements in generalized Lorenz-Mie theories: A commented reference database, Ann. Phys. (NY) **526**, 461 (2014).
[24] G. Chaussonnet and P. M. Bardet, Scattering of an ultrashort laser pulse by a spherical air bubble, Opt. Express **28**, 27358 (2020).
[25] S. Yadav, A. Devi, and A. K. De, Synergistic effect of Fano resonance and optical nonlinearity in laser trapping of silver nanoparticles, Phys. Rev. A **102**, 043511 (2020).
[26] G. Chaussonnet, L. Méès, M. Šormaz, P. Jenny, and P. M. Bardet, Modeling multiple scattering transient of an ultrashort laser pulse by spherical particles, J. Comput. Phys. **457**, 110696 (2022).
[27] M. I. Tribelsky and A. E. Miroshnichenko, Two tractable models of dynamic light scattering and their applications to Fano resonances, Nanophotonics **10**, 4357 (2021).