Course of nanophotonics in view of modernization of courses of electrodynamics: 4 years of experience

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Abstract

Education in area of electrodynamics of compound materials, especially electrodynamics of metamaterials (compound materials with magnetic response) requires deep review, modernization, and cooperation in order to follow the actual tendencies in science and technology. In this work I present my experience of giving/teaching my course, "Introduction to nanooptics", at Friedrich-Schiller University of Jena. I identify the main weak points in the education system in area of modern electrodynamics, and give my opinion about the optimum way of improving educational standards in this area.

Epigraph:
"It is necessary to reconstruct the textbooks and change some pedagogical methods in lecturing of electrodynamics. Namely, we should introduce four vectors E, D, H, B for all materials, and for vacuum also", Prof. V.G. Veselago

1. Introduction

Theoretical predictions and technological achievements have made possible, the realization of a wide class of artificial materials exhibiting a hitherto unseen magnetic response at high, in particular optical, frequencies. This, in turn, forced scientists to refresh an idea about materials with both negative dielectric and magnetic constants (left-handed materials) put forward by Prof. V. G. Veselago more than 40 Years ago. These attempts resulted in successful experimental demonstration of such material in RF and optical domains, which manifested start of the era of metamaterials.
From the beginning, theoretical considerations of the metamaterials were performed based on a commonly accepted approach of introducing the dielectric and magnetic constants in the frame of standard homogenization concept for Maxwell equations. It did not take too long time to realize, that this approach fails to describe the observed optical properties of the metamaterials forcing a reevaluation of the problem of homogenization of such materials and elaboration in a logic and self-consistent way to introduce the averaged optical parameters. The problem of homogenization is currently the main "driving force" to building a more or less unified approach to the description of electro-magnetic properties of metamaterials.
Huge amount of papers devoted to this topic have been published recently, among of them a very good overview of the problem [1]. However, a significant amount of papers violate fundamental physical requirements, which only emphasises the necessity of improving educational standards within the area of electrodynamics. Moreover, vast majority of the papers utilize numerical methods without appropriate attention to the logic structure of the model and to the connection of own theories to the earlier developed ones in area of compound materials.

In my opinion, a gap has now been established between University courses of electrodynamics and the knowledge which is necessary to successfully treat the problem of electrodynamics of the metamateri-

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als. In this presentation I would like to share my experience in attempting to fill this gap and to create a new approach to the teaching of the electrodynamics of metamaterials.

2. Peculiarities of the course

The course "Introduction to nanophotonics" has been created as a part of Master Program in the Friedrich-Schiller University of Jena and is given as an elective. One of the peculiarities of the course is in *introducing Maxwell equations*, which follows the approach accepted in course of theoretical physics of L. Landau and E. Lifshitz [2], is presented in Fig. 1

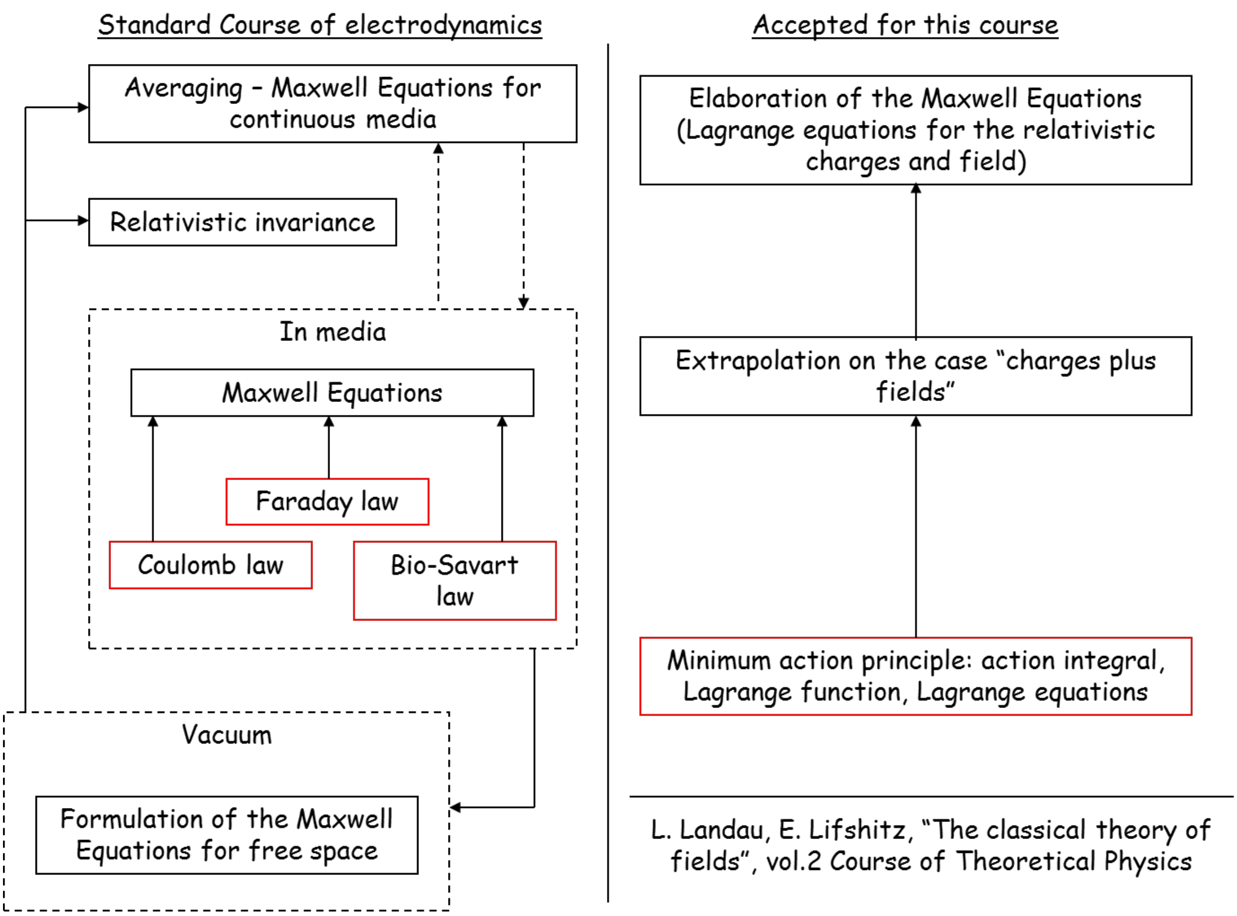

Fig. 1: Two ways of introducing of Maxwell equations: a) in standard University courses, b) in course of theoretical physics of L. Landau and E. Lifshitz.

In standard courses, from the very beginning macroscopic phenomena are considered, after that the microscopic equations are postulated and then homogenization is applied to get back to the macroscopic description – which in comparison with the approach of L. Landau and E. Lifshitz is not so logic. Moreover, relativistic invariance, which is a natural consequence in L. Landau and E. Lifshitz approach, has to be proven in standard courses. Hence, if homogenization procedure plays a significant role in the course (which has to be, but it is not at the moment for the standard courses) the approach of L. Landau and E. Lifshitz ought to be utilized.
A second peculiarity of the course is in teaching of the so called *Serdyukov-Fedorov transformations*, which plays a crucial role in understanding of basics of homogenization of Maxwell equations and gives a clear structured view of the different forms of representing Maxwell equations and the mutual relation between them. This knowledge is an absolute prerequisite for work in the area of electrodynamics of compound media; nevertheless, not only is excluded in standard courses, but very rarely appears in publications.

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The third peculiarity of the course is in the significant attention paid to the *multipole model of homogenization* [3]. This approach allows us, not only to describe practically all observable physical effects, but to present the description (in frame of the same unified approach), which is extremely important for the educational courses.
Final point is the necessity to include the basics of *quantum dynamics* in the courses. This is stipulated by the fact that the metamaterials consist of not only classical ingredient, but are more and more often a combination of classic (like plasmonic nano resonators) and quantum (like QD, CNT, or grapheme) parts. The dynamics of metaatoms consisting of coupled classic and quantum systems has to be naturally included which, in the course, has been done in the framework of the multipole approach.

3. Feedback from students

The course has been given to groups of first year master students over the last 4 years, has been evaluated and corrected according to the produced feedback. The course is seen as a first step in creating a more general course of modern electrodynamics, because of that it was very important to see how well the students understood and memorized the information. The conclusions are as follows:

1. In spite of higher level of complexity, the information is rather well received due to pedagogical consistency of the course.
2. The teaching has to be accompanied by seminars with examples explained from first principles using the new ideas; otherwise even such averagely-complex constructions, like multipoles were not fully understood.
3. The knowledge of the students, in the area of quantum mechanics is not satisfactory. The basics of quantum mechanics formalism based on density matrix approach have to be included in the course and also accompanied by appropriate and detailed examples.
4. The course has to be matched with the other ones, which requires a lot of systematic work. Unfortunately, the necessity of this work is not fully accepted by all teachers even in the same University.

4. Conclusion

The modern course of electrodynamics:

1. Has to be extended on the phenomena of artificial magnetization at high frequencies, where the magnetic effects before invention of metamaterials assumed to be impossible.
2. Has to be consistent with the basics principles like causality and passivity.
3. Has to include detailed consideration of homogenization procedure, different representations of Maxwell equations, Serdyukov-Fedorov transformations, and multipole approach.
4. Has to include basics of quantum dynamics, which is a prerequisite for the description of the very ingredients which the metamaterials consist of.
5. The self-consistency and clear logic of the course seems to be more important than the intention to present fully rigorous and complicated expressions. In other words, qualitative models for the students are much more important than learning of quantitative but inevitably more complicated methods from the beginning.

References

[1] C. Simovski, „Material parameters of metamaterials (a Review)“, Optics and Spectroscopy, 107, 726, 2009.

[2] L.D. Landau and E.M. Lifshits, *Electrodynamics of Continuous Media,* 2nd edition, Oxford, England: Pergamon Press, 1984.

[3] S.A. Tretyakov and I.S. Nefedov, Field-transforming metamaterials, Proceedings of *Metamaterials'2007*, pp. 474-477, Rome, Italy, 22-24 October 2007.

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