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Light scattering by systems of particles. Null-field method with discrete sources – theory and programs. With CD-ROM. (English) Zbl 1163.78002

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The well-written book is devoted to the light scattering of diverse particles encountered in practical applications. The fundamentals of the theory of electromagnetic scattering, the numerical techniques for analyzing the scattering problems, and the corresponding software including the simulation results are described in three chapters. A FORTRAN software package used for all discussed scattering problems is provided on a CD-ROM with the book. Because the book is written for physics and engineering students, and for practical researchers some mathematical details are not treated in the chapters but, the most important rules and theorems are summarized in four appendices. The development of the subject of the monograph is well-documented by a comprehensive bibliography. An Index contains the most important terms used in the book.

Chapter 1 starts in Section 1.1 with Maxwell's equations in the time and frequency domain and in the differential and integral formulation. Poynting's theorem and the time-averaged Poynting vector are deduced. The boundary and interface conditions for Maxwell's equations are introduced. The constitutive relations taking into account isotropic, anisotropic and chiral media and making the number of unknown scalar functions and the number of equations compatible are presented. The dispersion relation that relates the amplitude of the wave vector to the properties of the medium is introduced. The matrix form of Maxwell's equations with the K-matrix is derived and is simplified assuming a source-free medium. The description of the matrix includes the concepts of electric permittivity, permeability, conductivity, electric and magnetic susceptibility, and chirality.

The basic fields of the subject, the incident, the internal and the scattering field, are considered in the following three sections.

Special attention for the incident field is paid to the polarization because the polarization state of an electromagnetic wave is changed on interaction with a particle. Three ways are deduced to derive the polarization state of vector plan waves preparing the analysis of the scattered field. The vector spherical waves expansion of the incident field is deduced in order to prepare the derivation of the transition matrix (T-matrix) needed for the numerical solution by the null-field method described in Chapter 2. Especially, the expansion of Gaussian beams, needed for the scattering by particles illuminated by laser beams, in vector spherical wave functions is treated.

The approximation of the second field, the internal field, required for the numerical solution of the scattering problem by the null-field method, is discussed in Section 1.3. Regular vector spherical wave functions of the interior wave equation are used in the case of isotropic particles. New systems of vector functions are required for anisotropic and chiral particles, and these are developed as integrals over plane waves solving Maxwell's equations considering the inverse Fourier transform. Using the dispersion relation the three-dimensional integrals are reduced to two-dimensional integrals over the unit square for the electric and magnetic field. The formulas contain the above-mentioned isotropic media as a special case. The integrals are transformed into series representations for fields propagating in uniaxial anisotropic media resulting in vector quasi-spherical wave functions for anisotropic media and vector spherical wave functions in chiral media. In the last case the electromagnetic field is transformed, and left- and right-handed circulary polarized waves have to be considered.

In Section 1.4 the transmission boundary-value problem for the electromagnetic scattering by dielectric particles with the two transmission conditions and the Silver-Miller radiation condition is formulated focusing on the scattered field in the far-field region. In order to solve the problem in the first instance representation theorems for the electromagnetic fields, the so-called Stratton-Chu formulas, are formulated and compared to a rigorous proof, given in [*D. Colton* and *R. Kress*. Integral equation methods in scattering theory. New York: Wiley, (1983; Zbl 0522.35001)], an alternative proof is presented. The surface integral equations of Stratton-Chu are valid for homogeneous particles. Additionally, for inhomogeneous particles a volume-integral representation is derived.

Applying the Stratton-Chu theorem to the surface and the bounded domain results in Huygens principle and the null-field equation or so-called extinction theorem, respectively. The last is used in the null-field method to derive integral equations for the surface field while the scattered field is computed by means of the Huygens principle. The integral representations for the far-field pattern and the amplitude matrix describing the transformation of the transverse components of the incident wave into the transverse components of the scattered wave in the far-field region are deduced. The measurement of the amplitude matrix quantities is a complicated experimental problem. Thus, in order to be able to better compare computational and measurement results phase and extinction matrices, and optical cross sections are introduced.

In Section 1.5 the T-matrix that relates the expansion coefficients of the incident and scattered fields is introduced. The properties of the T-matrix are studied. The scattering characteristics can be readily calculated if the transition matrix is known. Other topics are randomly oriented particles, the optical theorem, and orientation-averaged extinction and scattering matrices.

Following the authors, the null-field method has advantages in comparison to classical methods like finite-difference methods, finite element methods, or integral equation methods in terms of efficiency, accuracy, size parameter range, and especially in the computations for thousand of particles in random orientation.

Based on the theory of Chapter 1 the essential steps of the null-field method are outlined in detail and separately in Chapter 2 for homogeneous and isotropic, for homogeneous and chiral, for homogeneous and anisotropic, for inhomogeneous, for layered, for multiple, for composite and for complex particles as well as for particles on or near an infinite surface. Convergence and instability problems for instance caused by deformed particles and large size parameters are treated by modifications of the null-field method, such as the use of multipole spherical expansions or the Gram-Schmidt orthogonalization exploiting the unitary property of the ill-conditioned T-matrix. The simplification of the matrix equations of the null-field theory to the corresponding equations of the Lorenz-Mie theory in the case of spherical particles is outlined.

The last Chapter is devoted to simulation results for the scattering problems presented in Chapter 2 using and describing an own package for the T-matrix and some other electromagnetics programs. A concise description of the own T-matrix code is given. The theoretical bases and the fields of application of the other electromagnetics programs including the disadvantages are presented. The other electromagnetics programs are used to verify the accuracy of the new T-matrix code.

In four appendices mathematical details about the used spherical, wave and vector wave functions, and the computation of some special used integrals are summarized.

Reviewer: Georg Hebermehl (Berlin)

MSC:

78-02 Research exposition (monographs, survey articles) pertaining to optics and electromagnetic theory

78A45 Diffraction, scattering
78M25 Numerical methods in optics (MSC2010)
65D30 Numerical integration
65R30 Numerical methods for ill-posed problems for integral equations
35Q60 PDEs in connection with optics and electromagnetic theory
35P25 Scattering theory for PDEs

Keywords:

light scattering; Maxwell's equation; polarization; incident field; scattered field; internal field; transition matrix; T-matrix; null-field method, Stratton-Chu formulas; chirality; homogeneous particles; isotropic particles; chiral particles; inhomogeneous particles; layered particles; multiple particles; composite particles; complex particles: extinction theorem; Huygens principle; Silver-Miller radiation condition; Lorenz-Mie theory

Software:

NFM-DS

Full Text: DOI