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Heterogeneous particles with internal inclusions of different chemical composition and sizes: verification of concept of effective-medium approximation

J. Dlugach (1) and M. Mishchenko (2)

(1) Main Astronomical Observatory of the National Academy of Sciences of Ukraine, Kyiv, Ukraine (zhanna.dlugach@gmail.com), (2) NASA Goddard Institute for Space Studies, New York, USA (michael.i.mishchenko@nasa.gov)

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For a long time, the concept of the unrestricted effective-medium approximation (UEMA) has been widely used when analyzing the optical properties of heterogeneous materials. In fact, if it proves to be sufficiently accurate then it allows one to significantly simplify the calculation of light scattering characteristics of small heterogeneous particles. In our previous work, we introduced the notion of modified unrestricted effective-medium approximation (MUEMA) and modified unrestricted effective-medium refractive index (MUERI). We validated this concept by comparing numerically exact superposition T-matrix results obtained for a spherical host randomly filled with a different number of internal inclusions of different sizes and Lorenz–Mie results for a homogeneous spherical counterpart. The refractive indices of the host and the inclusions were fixed at 1.33 and 1.55, respectively. Based on that comparison, the range of possible applicability of MUEMA was determined, and it was concluded that if the MUEMA is valid then the MUERI is likely to be close to that predicted by the Maxwell-Garnett mixing rule.

Here, given the great practical importance of the problem of electromagnetic scattering by discretely heterogeneous objects, we analyze if the MUEMA is applicable over an extended range of the refractive indices of hosts and internal inclusions. Our study is based on the results obtained by using the superposition T-matrix method and the parallelized FORTRAN-90 program (http://www.eng.auburn.edu/users/dmckwski/scatcode), as well as by applying the Lorenz–Mie theory. The computations were performed for such refractive index combinations: 1) m_{host} = 1,4: m_{incl} =1, 1.5, 1.6; 2) m_{host} = 1,5: m_{incl} =1, 1.4, 1.6; 3) m_{host} = 1,6: m_{incl} =1, 1.4, 1.5. We fixed the value of the size parameter of the spherical host at X = 10 and used four values of the size parameter for the spherical inclusions x = 0.3, 0.5, 0.7, 1. The number of inclusions was chosen such that the volume fraction of the inclusions was approximately the same in all cases considered (about 10% and 20%), and the wavelength was λ = 0.6283 μm. The results of our computations demonstrate, in particular, that: (i) the numerical inaccuracy of the MUEMA grows with increasing the difference between the refractive indices of the host and the inclusions; (ii) if the concept of MUEMA is valid then increasing the number of inclusions results in a greater difference between the values of the refractive indices derived by using the MUEMA and the Maxwell-Garnett formula; (iii) the concept of MUEMA is valid over a broader range of inclusion size parameters for integral optical characteristics (such as the scattering cross section and asymmetry parameter) than for the elements of the scattering matrix.