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PROPAGATION OF ELECTROMAGNETIC WAVES THROUGH NON-HOMOGENEOUS MEDIA

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Abstract: The most significant results we obtained on the propagation of electromagnetic waves through non homogeneous media are summarized.

1. Introduction

A few years ago we devised a model scatterer suitable for a systematic study of the optical properties of aerosols and in particular of the effects of the anisotropy and of the possible aggregation of the constituent particles. Indeed, our model scatterer is built as a cluster of spherical objects of arbitrary radii and refractive indexes; the spheres need not be homogeneous and their relative positions are arbitrary to a large extent. The scattering of electromagnetic waves by such composite scatterers is dealt with through the use of multipole expansions to describe both the incident and the scattered field as well as the field within the component spheres [1, 2]. The resulting forward scattering amplitude has very simple transformation properties under rotation of the coordinate axes. This allows us to calculate very easily the macroscopic optical properties of a low-density dispersion of clusters even when they are randomly oriented. In fact, we are able e.g. to study the changes of the spectrum of a dispersion of spherical particles, both homogeneous and non-homogeneous [3,4], when they undergo various stages of aggregation and even when they change their mode of aggregation in, analogy to what happens in chemical reactions [5].

In the last year we started an attempt to extend our study to intermediate and high-density dispersions through a modified version of the effective medium theories [6]. Essentially the effective medium theories substitute the actual dispersion with an effective medium whose dielectric properties are calculated so as to compensate exactly for the scattering produced by the particles. Our particular work in this field consists in treating a dispersion of metal spheres with size-parameter bigger than that usually dealt with within the Bruggemann scheme [7] and yet sufficiently small to ensure the validity of the dielectric description of the medium. Accordingly we used the full Mie expansion and as a further improvement included some kind of correlation e.g. that produced by aggregation phenomena or by an exclusion hole around each sphere. This amounts to using a mixed scheme midway between that of Bruggemann and that of Maxwell-Garnett. Some of our preliminary results will be illustrated in Section 3.

2. Theory

All the information on the propagation of electromagnetic waves through a low-density dispersion of scatterers is contained in the matrix of the refractive index [8]

$$\mathcal{N}_{\eta'\eta} = \delta_{\eta'\eta} + \frac{2\pi}{Vk^2}\sum_{\nu} f_{\nu,\eta'\eta} \qquad (1)$$

where the sum runs over all the scatterers within the volume V and

$$f_{\nu,\eta'\eta} = \mathbf{u}^*_{\eta'} \cdot \mathbf{f}_{\nu,\eta} = \frac{1}{8\pi ki}\sum_{\nu}\exp[-i\mathbf{k}\cdot\mathbf{R}_{\nu}]\sum_{pLM} W^{(p)}_{LM}a^{(p)}_{LM} \qquad (2)$$

In eq. (2) $\mathbf{u}_{\eta'}$ is the polarization vector and $\mathbf{f}_{\nu,\eta}$ the forward-scattering amplitude of the ν-th scatterer; in turn the $W^{(p)}{}_{LM}$'s are the multipole amplitudes of the incident plane-wave field and the $a^{(p)}{}_{LM}$'s are their counterparts for the scattered field. The superscript p is a parity index which distinguishes the magnetic multipole fields (p=1) from the electric ones (p=2) [9]. When the scatterer is a cluster of spheres the multipole amplitudes of the scattered field are

$$a^{(p)}_{LM} = -\sum_{p'L'M'} S^{(p,p')}_{LM,L'M'}V^{(p,p')}_{L'M'}$$

where the S's are defined in ref.[3]. The most important feature of the S's is that under rotation of the coordinate axes they transform according to the representations of the full rotation group. As a consequence, once the S's are known for a cluster of given orientation they are immediately known for any other cluster of different orientation, and the sum in eq.(1) can be performed analytically.

For intermediate and high-density dispersions, the procedure outlined above does not yield reliable results because the multiple-scattering processes become more and more important. A possible way to overcome this difficulty is to resort to the effective medium theories such as the well-known mixing rules of Bruggeman, and of Maxwell-Garnett. The general principle on which these rules are based was outlined in sect. 1 and, as our work in the field is still in progress, we defer our further comments to the next section where some our preliminary results will be presented.

3. Results and Discussion

Fig. 1 we report the real (1a) and the imaginary part (1b) of $\mathcal{N}_{11}$ for a low-density dispersion of binary clusters both oriented alike (solid lines) and at random (broken lines) versus the size parameter, $x=k\rho$, of the constituent spheres, which are homogeneous with $n=1.3$. All the curves are normalized to the corresponding quantities of a dispersion of independent spheres with the same density and refractive index and show not only a noticeable dependence on the orientation but also that for a cluster of given geometry there exist a value of the size at which this dependence disappear. Our experience suggests that this pseudo-spherical behavior is bound to appear for some value of the size when the clusters have a definite symmetry.

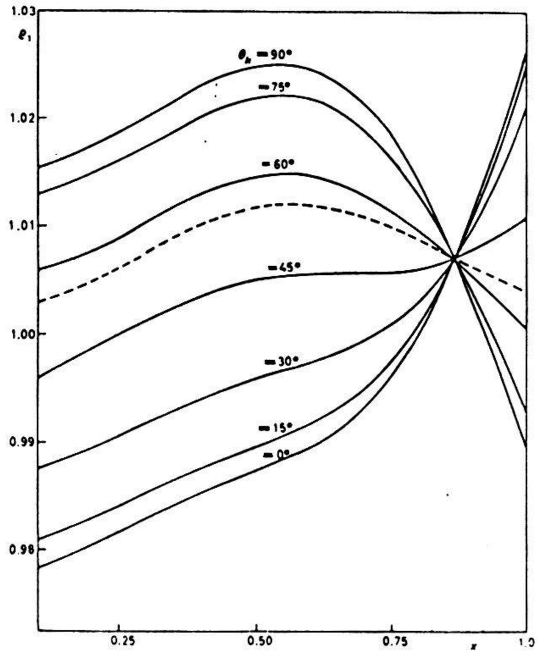

Fig. 1a

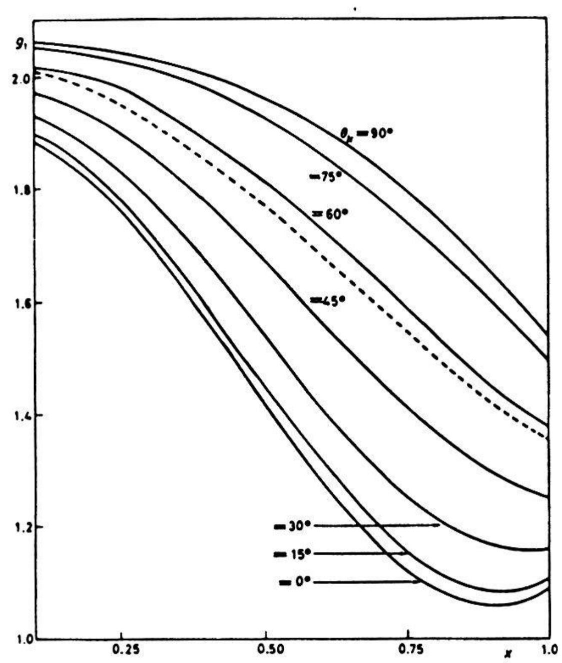

Fig. 1b

As anticipated in sect. 1, we also dealt with dispersions of layered spheres which we treated as explained in ref.[3]. In short, we kept constant the dielectric function within each layer and between each pair of them interposed a transition layer, as thin as possible, within which the radial dependence of the dielectric function is taken so as to ensure the continuity of ε and of its radial derivative. We considered in this way spheres with a diffuse surface, metal spheres with a dielectric or metallic coating and dielectric spheres with a metallic coating. The dielectric function of the metal was described by a free-electron Drude function, while that of the dielectric was described by a damped oscillator function. The most striking result is shown in fig. 2 which refers to spheres of MgO coated with Al with a total radius of 50Å. It is quite evident that the absorption peaks of the dispersion of single spheres (solid lines) shift according to the thickness of the coating: thus

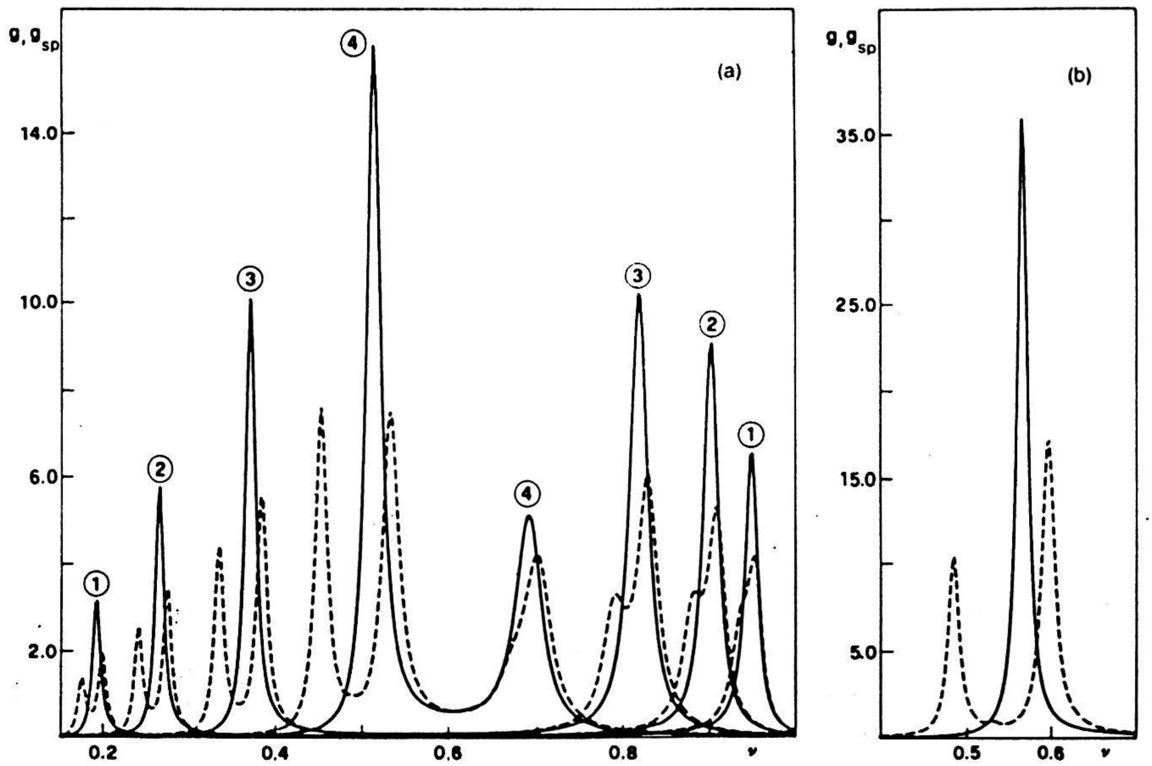

Fig. 2

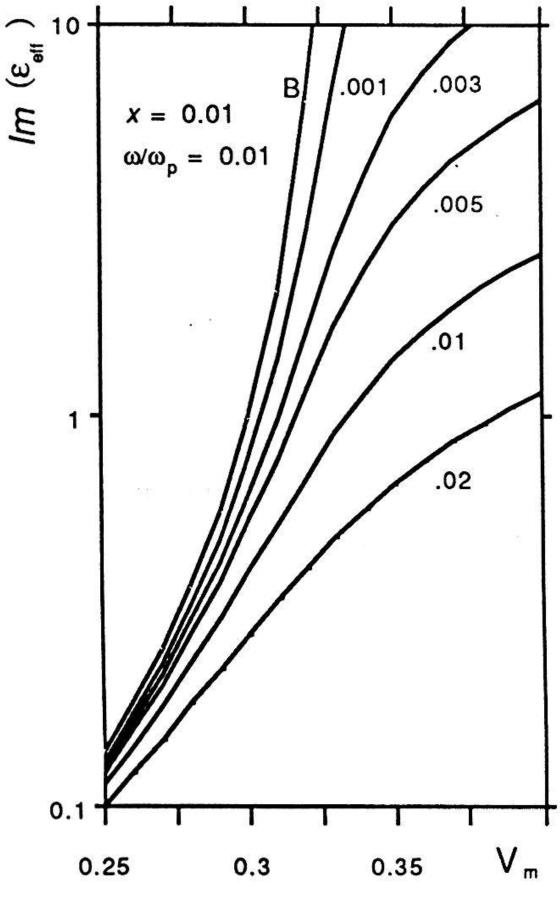

Fig. 3

this feature can be, in principle, used to obtain a selective absorption at any frequency within a given range. Nevertheless this effect can be greatly weakened if a considerable percentage of the spheres aggregate (broken lines).

At last we give here an anticipation of our present attempt to use at best the potentialities of the effective dielectric constant methods beyond the mixing rules of Bruggeman and of Maxwell-Garnett. In fig. 3 we present our results for one of the conceivable intermediate models between that of Bruggeman and that of Maxwell-Garnett. This model consists of an admixture of metal and dielectric spheres (these latter with dielectric constant $\varepsilon=1$). Around each metal sphere we put a exclusion hole in the form of a layer of variable thickness with dielectric constant $\varepsilon=1$.The curves in fig. 3 are labeled by the percentage of volume occupied by the exclusion holes. The curve labelled B refers to the conventional Bruggeman rule. All the spheres were dealt with through the full Mie theory. The main result of our calculation is a dramatic shift of the percolation threshold as a consequence of the correlation of exclusion we forced on the system.

4. References

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