# Problem of light scattering in complex media

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**Abstract**. This work includes discussion about different types of interaction between electromagnetic radiation and various materials. Field reorganization in ordered media is considered, also impact of scatterers' size and distance between them on the scattering process is discussed. Phase diagram for scattering regimes in complex media is suggested.

## 1. Introduction

In the end of XIX century the influence of radiation on the medium properties was studied systematically due to the photoelectric effect. The internal and external photoelectric effect is the result of interaction between light and medium, which leads to electrons fly out the medium and to the ionization. Thus, even weakly conductive media become conductors and their properties change significantly in electromagnetic fields. By the example of photoelectric effect the importance of interaction between light and medium becomes more evident.

Interaction between radiation and materials can be divided into two groups: absorption and scattering. A lot of publications concern absorption of electromagnetic radiation [1], this problem is well studied. Depending on the radiation range, the interaction between electromagnetic radiation and medium can be caused by absorption due to rotational and vibrational terms of molecules (microwave, terahertz, infrared ranges), or due to transitions between molecule electron levels (visual range), ionization by UV and X-rays, and also due to Compton scattering. In comparison with absorption, scattering of radiation is weakly studied.

## 2. Electromagnetic scattering in ordered medium

Propagation of radiation even in homogeneous media is rather complex. While radiation penetrate the material, it scatters and shifts in spectrum, which depends on the spatial orientation of scattered radiation.

But in fact, the complexity of radiation interaction with medium increases with the presence of structural material (also periodical). Thus, collective effects of coherent interaction (multi-ray interference) should be considered while studying scattering, which are so strong in ordered media, such as metameterials, photonic crystals, and composite materials [2].

Structure effect is more significant in the electromagnetic range, where wavelength is comparable to the size and the period of the structure. Until recently it was believed that spatial periodicity has little effect on scattering in such media, but last studies show the opposite.

For structures with long-range correlations (which means the long-range correlations of properties), the weak processes (for example, scattering of radiation), the results of which add coherently with each other, become decisive. In this case electromagnetic field is redistributed inside the material, also the field localization occurs [3-5]. Today electromagnetic field interaction with optical materials, which have long-range correlations of optical properties also when multiple scattering is taken into account, is a complicated and poorly understood problem. Therefore, in order to study terahertz (THz) waves interaction with quasi-crystal media and metamaterials, the numerical methods are widely used. The approaches, which account the structure factor, are the most important in this case.

## 3. Approaches to describe the radiation scattering

Nowadays there are various methods to account the material structure for studying the radiation-material interactions. Figure 1 shows the basic approaches used in different ranges of electromagnetic spectrum.

Historically, radiation transfer theory was derived first. In different modifications it is used for wide range of electromagnetic waves: from microwaves to X-rays [6]. This method is based on the radiation transfer equation, which should be completed by the appropriate “closed” equations for the scattering phase function (scattering indicatrix). Thus, in this sense, the radiation transfer theory is not completed and needs additional assumptions about the character of radiation propagation in the media.

Along with the phenomenological method, the radiation transfer equation can be derived from Maxwell equations.

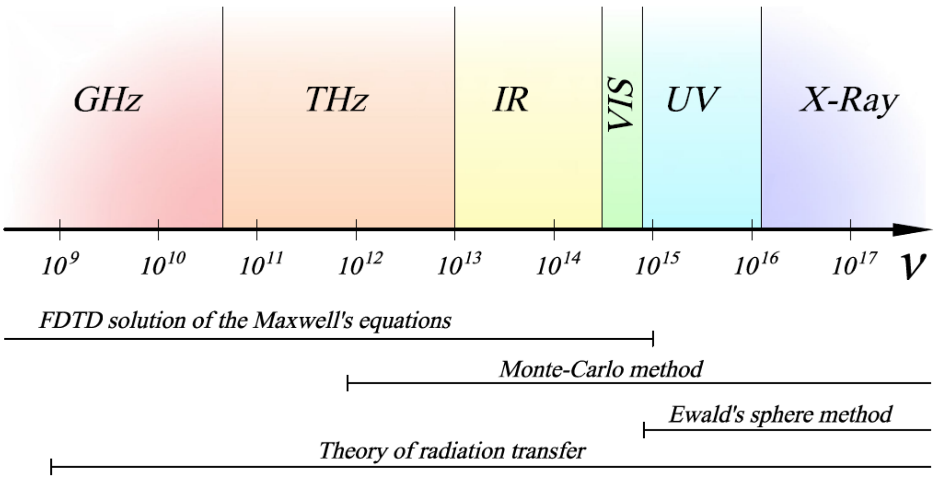


**Figure 1.** Application fields of the basic methods for description of the field propagation within the structures with long-range correlations.

In radiation transfer theory in case of rarified disordered media without short- and long-range correlations between spatial geometry and material properties, various *a priori* approximations estimating single scattering phase function are used. The contribution of multiple scattering is assumed to be negligible.

With the growth of packing density, in other words, with the decreasing of the distance between scatterers, multiple scattering shows a significant impact. Thus, uncertainty appears even in the *a priory* choice of scattering phase function for complex media, and especially for media with long-range correlations of properties. It is necessary to use basic theoretical principles for radiation transfer computations. Generally, the most frequently used methods for this purpose are computational electrodynamics [2,3-5,7], Monte Carlo numerical simulation considering the quantum nature of light [6,8,9], and the Ewald concept [10,11], which was developed for X-rays transfer and spread on the optical range.

Using these methods, it is unnecessary to get *a priory* estimation of the scattering character. Moreover, it is possible to find regularities in radiation transfer in different media. Figure 2 illustrates the discussed problem of scattering influence on the radiation transfer character in medium. The proposed picture from figure 2 is the phase diagram of scattering regimes developed for complex media.

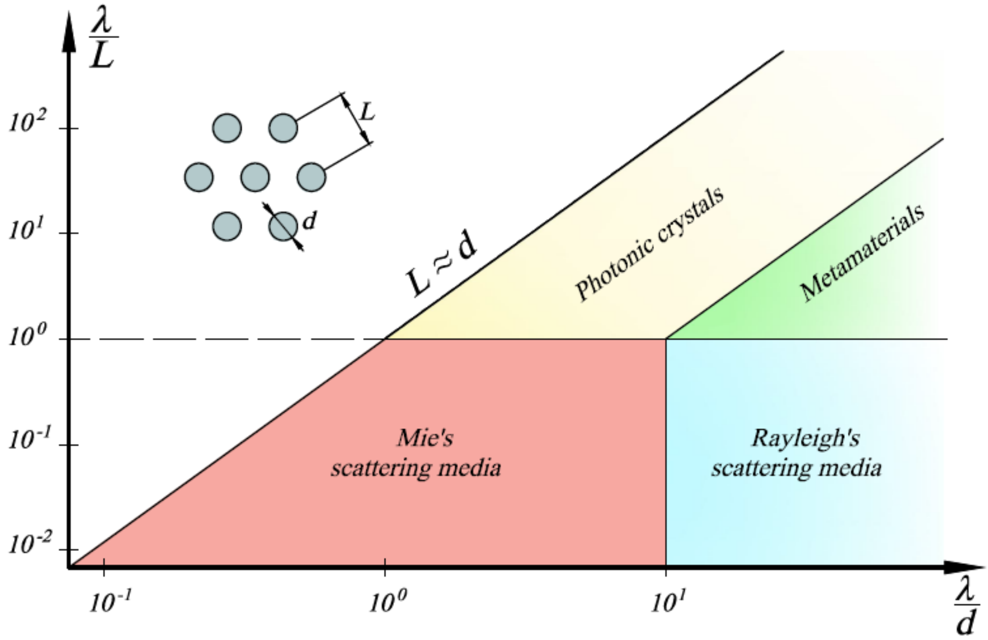


**Figure 2.** Phase diagram for possible scattering regimes.

When the distance between scattering particles or the correlation length of structure is much larger than wavelength, scattering has the incoherent character. Such process is well described by the Mie and Rayleigh scattering theories, thus, no difficulties can be found in this case.

Otherwise, description of the coherent scattering is more complicated. Depending on the relation between wavelength and correlation length, coherent scattering may be described by the photonic crystal theory or the theory of metamaterials. These approaches were developed relatively recently and today attract significant attention.

It should be noticed, that methods of radiation transfer theory is ineffective in case of photonic crystal and quasi-crystal media, metamaterials, because of uncertainty of scattering phase function used in order to complete radiation transfer equation. In the same time, using methods of computational electrodynamics, the visualization of field redistribution inside the scattering material becomes possible, as well as determining of the scattering phase functions and establishment of regularities for radiation transfer in complex media.

## 4. Conclusion

Possible types of interaction between electromagnetic radiation and scattering medium are analysed in dependence of different radiation frequency ranges. Also the impact of scattering structure on the radiation propagation is discussed. Phase diagram for scattering regimes in complex media was suggested for generalization of different scattering theories and approaches. Using this diagram, all scattering materials can be classified unambiguously and the radiation transfer can be considered in a new way.

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