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SCATTERING OF ELECTROMAGNETIC WAVES BY CHARGING CLOUD OF PARTICLES

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1 Introduction

In the last years a scattering of electromagnetic waves by charging clouds of particles is of great interest. First of all this is connected with the observing of anomalous strong reflection of radiowaves by charging clouds.

In this paper it is shown, that the effects of localization may be observed in the scattering of electromagnetic waves on the plasma formations, arising in a cloud of charged particles in a atmosphere. The phenomenon of localization in classical systems, such as microwave or light propagation in random media, has been discussed in a number of papers [1,2]. The criterion of localization is $\ell_s/\lambda \le 1$, where ℓ_s is the elastic mean-free-path, λ is the wavelength. Besides an absorption must be small, i.e. the corresponding inelastic mean-free-path ℓ_a must be much more than the wavelength λ. Achievement of these conditions in condensed media is the difficult problem. Usually systems lioke paints, porous media, etc. are proposed, where the condition $\ell_s \ll \ell_a$ is carried out. However a strong localization in these experiments is not observed. Early localization of microwave radiation is found in random mixtures of metallic and dielectric spheres [3].

2 Physical properties of the system

The considered physical system is a charged cloud of aerosol particles. Charged aerosol clouds may be obtained in the laboratory [4]. It is known, that charged particles scatterer the electromagnetic waves much more strongly than the noncharged case. The scattering section of a charged particle is proportional to the square of the elementary charge number Z. Therefore the scattering section is increased by a factor 10^6-10^8 if $Z \simeq 10^3-10^4$. However this is still insufficient in order to be registered by radiolocation devices. In a cloud of charged particles the corona discharges could exist in the avalanche or streamer forms [4]. The avalanche corona takes place in the case when the charge of an individual particle exceeds some critical value q_{cr}, at which the emission of charges begins. The concentration of electrons in the avalanche is equal to $n_e = 10^{12}-10^{13}$ cm^{-3}. The streamer discharges in air are plasma needle formations by length L up to a few centimeters at the atmosphere pressure. The density of charges in the streamers, the radius of streamers and the volume density of streamer formations are equal to $n_e = 10^{14}-10^{16}$ cm^{-3}, $a = 10^{-2}$cm, $N = 1$ cm^{-3} respectively.

The cross sections of scattering σ_s and absorption σ_a and also the length of the elastic mean-free-path ℓ_s and inelastic mean-free-path ℓ_a may be expressed in terms of the polarizability of the plasma formations in the field of electromagnetic waves [5]

$$\sigma_s = \frac{8\pi}{3} k^4 \langle|\alpha|^2\rangle, \ \sigma_a = 4\pi k \langle\alpha''\rangle ; \ \ell_s = \frac{1}{N\sigma_s}, \ \ell_a = \frac{1}{N\sigma_a} ; \ \alpha = \alpha' + i\alpha'' \qquad (1)$$

where α is the polarizability, k is the wave number, N is the concentration of plasma formations, sign $\langle\ \rangle$ means the averaging on the orientation of needles.
The polarizability is determined by the dielectric constant of the plasma formations, of which real and imaginary parts have the form:

$$\varepsilon' = 1 - \frac{\omega_p^2}{\omega^2 + \nu^2}, \quad \varepsilon'' = 4\pi \frac{\sigma}{\omega} = \frac{\nu \omega_p^2}{\omega(\omega^2 + \nu^2)}, \qquad (2)$$

where $\omega_p = (4\pi e^2 n_e / m)^{1/2}$ is the plasma frequency, ν is the collision frequency, σ is the conductivity, ω is the frequency of the electromagnetic wave.
The characteristic parameters of plasma formations, determining the frequency range of localization, are equal to: $\omega_p \simeq 5{*}10^{11} - 5{*}10^{12}\ c^{-1}$, $\nu \simeq 10^7 - 10^8\ c^{-1}$, $L \simeq 1$ cm, $a \simeq 10^{-2}$ cm, $N \simeq 1$ cm^{-3}.

3 Frequency dependency of σ_s and σ_a .

Let us consider as a model of plasma formations the cylindrical needles with length L and radius a with $L \gg a$. The polarizability of such needles has the form [5]:

$$\alpha_{x,y,z} \simeq \frac{La^2}{4} \cdot \frac{\varepsilon - 1}{1 + (\varepsilon - 1) m_{x,y,z}}, \qquad (3)$$

where $m_z = \frac{3}{4}\left(\frac{a}{L}\right)^2 \left(\ln \frac{4L}{a} - \frac{7}{3}\right), \ m_x = m_y = \frac{1}{2}(1 - m_z)$.

Note, that the axes of plasma formations are orientated randomly. Inserting (3) to the expressions (1), we obtain the dependences σ_s and σ_a versus the frequency ω .
For the ellipsoid form of plasma formations, an exact solution of the polarizability exists [5]:

$$\alpha_{x,y,z} = \frac{La^2}{3} \cdot \frac{\varepsilon - 1}{1 + (\varepsilon - 1) m_{x,y,z}}, \qquad (4)$$

where $m_z \simeq \left(\frac{a}{L}\right)^2 \ln \frac{L}{a}, \ m_x = m_y = \frac{1}{2}(1 - m_z)$.

In Fig.1 the dependency of functions $\lg(\sigma_s/\sigma_a)$ and $\lg(\sigma_s N/k)$ on the $\lg(\omega_p/\omega)$ are presented for the ellipsoidal needles with parameters: $\omega_p = 10^{12}\ c^{-1}$, $\nu = 10^7\ c^{-1}$, $L = 1$ cm, $a = 10^{-2}$ cm, $N = 1$ cm^{-3}. It is seen from figure that the localization coditions ($\sigma_s/\sigma_a \gg 1, \sigma_s N/k \geq 1$) are fulfilled in the VHF range at frequences order of 20 GHz. The optimum frequency ω_{opt} at which localization conditions are fulfilled exists. Optimum frequency is decreased at the increasing of plasma formation length L. A picture for cylindrical needles is analogical, however the optimum frequency slightly is lower.
As a model of avalanche plasma formations a conducting spheres may be considered. The polarizability of such spheres with radius

has the form [5]:

$$\alpha = a^3 \frac{\varepsilon - 1}{\varepsilon + 2} \qquad (5)$$

In Fig.2 the dependences $lg(\sigma_s/\sigma_a)$ and $lg(\sigma_s N/k)$ versus the function $lg(\omega_p/\omega)$ are are presented. The parameters of spheres equal to: $a = 10^{-1}$ cm, $\omega_p = 10^{11}$ c^{-1}, $\nu = 10^{1}$ c^{-1}, N = 1 cm^{-3}. It is seen that the narrow range of frequencies also exists, at which localization takes place. The optimum frequency in this case equal to ω_o = 57 GHz. For others frequences the observation of localization is complicated because of strong decreasing of scattering section σ_s. The window of localization become wider at the increasing of concentration N. The increasing of spheres radius leads to the decrease of optimum frequency. At the radius smaller than a certain value localization is absent for all frequencies.

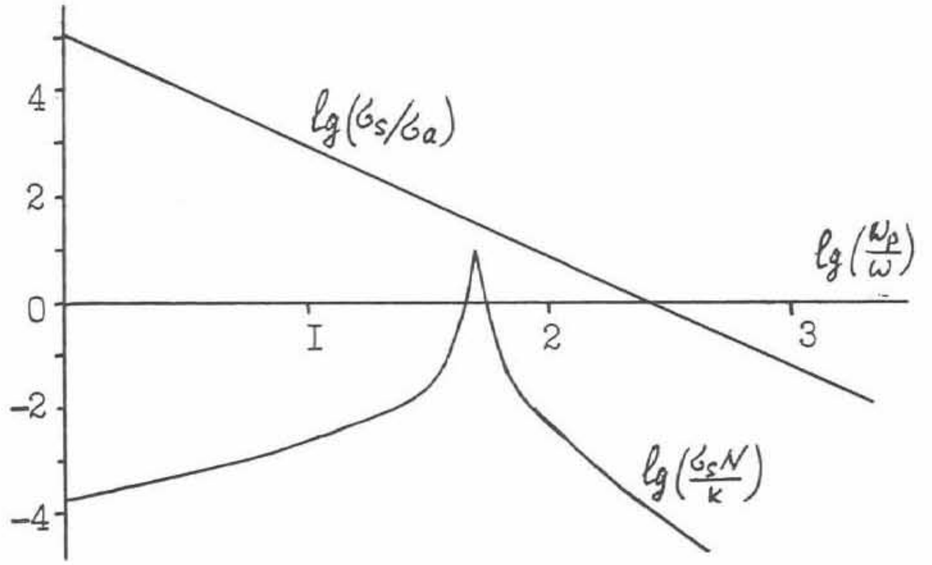

Fig.1

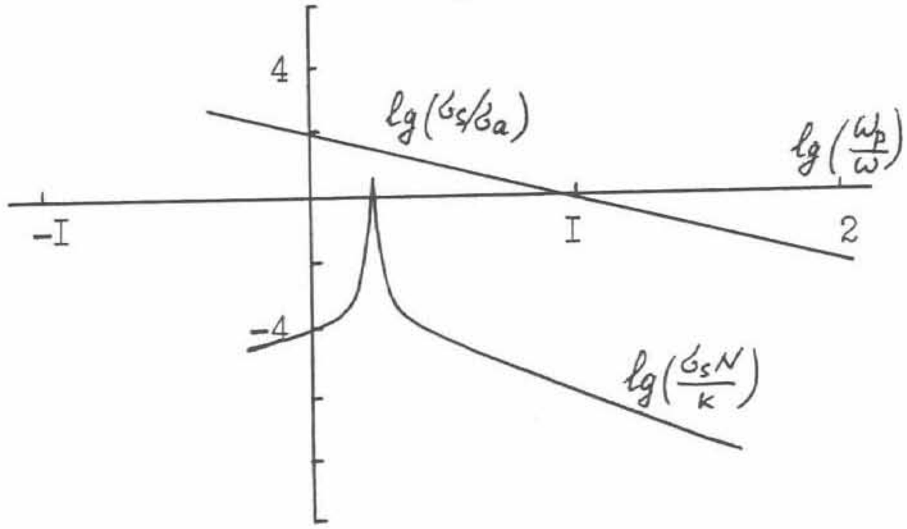

Fig.2

4 Discussion and conclusion

Thus, in the system of plasma formations, arising in the charged cloud of particles, the phenomenon of localization of electromagnetic waves takes place. Physically this corresponds to the vanishing of the diffusion coefficient for the waves. The effect of localization may be observed experimentally at the investigation of back scattering of electromagnetic radiation. The occurrence of localization is also established from measurements of the absorption coefficient [3].

The streamer formations arise also in the ordinary corona discharge in a atmosphere and in the cover of lightning channel. Therefore the effect of localization could be observed at the location of these discharges in the VHF range.

The effect of localization may be also cause the strong reflection of radiation with a frequency 50 MHz from the polar mesospheric clouds in the ionosphere, placed on the height 86 km [6]. It is known, that the mesospheric clouds consists of charged particles with concentration $N \simeq 10\ cm^{-3}$.

The frequency region of localization is determined by the parameters of plasma formations and of their concentration. However these parameters depend also on the gas composition and pressure. So, the conductivity of streamers in clear nitrogen is essential more than in the air. Therefore the frequency range of localization could be changed owing to changing of characteristics of the medium.

Note, that in many cases localization takes place only in a narrow range of frequencies. This needs the exact tuning of frequency of electromagnetic radiation. This peculiarity of localization is observed also in the experiment [3]. Note that the window of localizatiopn in the case of needles is wider than for the spheric scatterers. Besides for the needles two windows of localization at various frequencies exist. Thus, for the case considered in fig.1, the second window corresponds to the frequency ω_o = 725 GHz. This property in a diagnostics of scattering medium, particularly, at the determining of relation L/a of scatterers, may be used.

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