Study of orientation characteristics of model crystalline aerosols by holographic method

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Received January 5, 2000

Peculiarities and capabilities of holographic study of orientation characteristics of atmospheric crystalline aerosol are considered. A laboratory setup was developed, experiments on holographic recording of model aerosol were conducted, and the data on orientation of aerosol particles in electric field were obtained. The chosen holographic scheme provided the resolution sufficient for studying crystals in the size range corresponding to crystalline clouds.

Introduction

The atmosphere contains nonspherical aerosol particles of different nature (salt crystals, particles of anthropogenic origin, ice crystals, etc.) Crystalline clouds refer to aerosol formations consisting of ice crystals of different shape, as a rule, with pronounced anisotropy of geometric dimensions (see, for example, Ref. 1). In contrast to droplet aerosols, whose optical properties mostly depend on the refractive index and size spectrum of particles, the optical properties of crystalline aerosols significantly depend on the particle shape and orientation relative to the zenith and azimuthal angles as well.

One of the problems arising, when studying propagation of natural and laser radiation through crystalline aerosols,[2–5] is determining the relation between the orientation of aerosol particles and polarization characteristics of scattered radiation. Now the orientation of particles is usually determined indirectly from polarization of the scattered radiation. This method is based on some assumptions, requires *a priori* information on aerosol, and leads to large errors. Therefore, the problem of development of direct methods for remote determination of aerosol particle orientation is rather urgent.

To solve this problem, we propose to use pulsed holography. Actually, for a laser pulse (10–50 ns) this method allows remote recording of the information on dimensions, shape, and spatial orientation of each individual particle in the volume of a disperse medium under study. Peculiarities and restrictions of holographic methods have been studied quite well (see, for example, Refs. 6–8). The possibility to determine not only geometric characteristics of particles, but also optical ones by holographic methods was demonstrated as well (see Refs. 9 and 10).

In this paper, we describe a laboratory setup and the experiments on determining the orientation of particles of a model aerosol in the electric field by the holographic method in order to reveal peculiarities and capabilities of holography in solution of the formulated problem.

Crystalline aerosol modeling

As an object to be modeled, we chose ice crystals contained in atmospheric clouds. It is well-known that prevailing particles in the clouds are plates and columns[1] of sizes from 10 to 10^3 μm.

Generation of model aerosol ice crystals requires creation of complex, bulky, and expensive equipment (see, for example, Ref. 3). In our work we used crystalline powders corresponding to the above-mentioned dimensions and shapes of actual particles. Besides, for more close correspondence to the particles under modeling and to change their orientation by electric field, we selected model crystals possessing dielectric properties.

Among the crystal powders under study, the hydroquinone crystals mostly correspond to the above criteria. The hydroquinone particles have a crystal shape of columns (Fig. 1*a*), and they are semitransparent to the visible radiation. The size distribution of the particles was determined with the help of an optical microscope. The error of size measurement was 5 μm. Histograms of the hydroquinone particles distribution by two dimensions (length and thickness) are shown in Figs. 1*b* and *c*.

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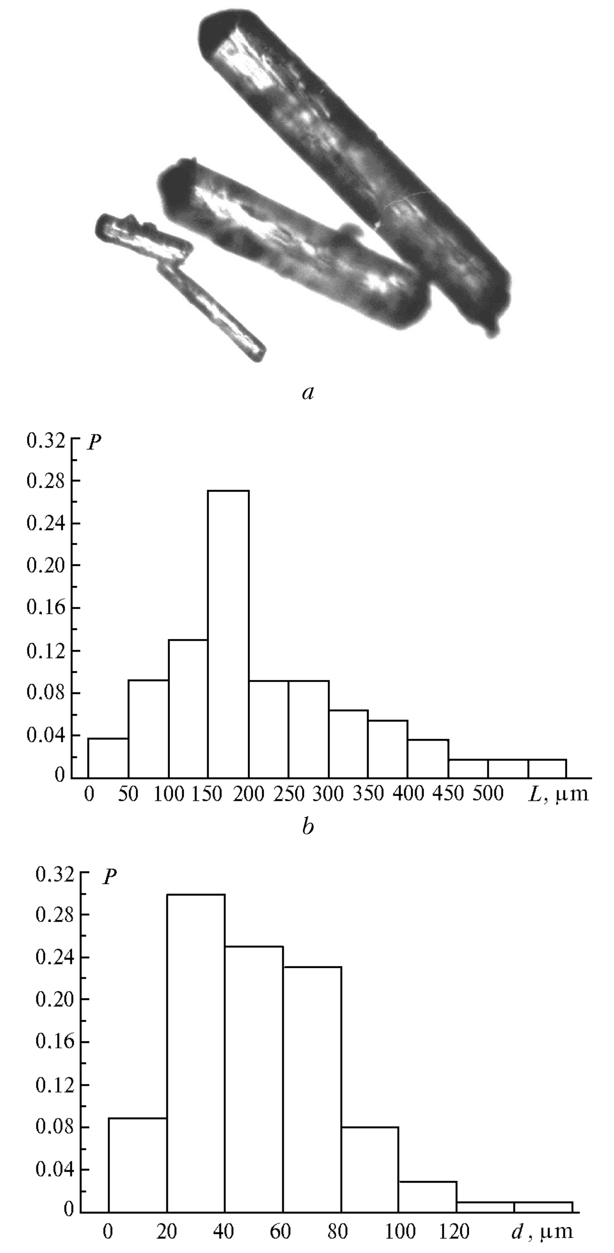

Fig. 1. Photograph (*a*) and histograms of size distribution of model particles: by the largest (*b*) and smallest (*c*) dimensions; *P* is the fraction of particles with dimensions falling in the corresponding range.

Hydroquinone crystals were injected into an object chamber with the help of a device shown in Fig. 2. The hydroquinone powder was placed in conic feed chamber *3* about 0.3 liter in volume and having two holes each 3 mm in diameter. Air was pumped in one of these holes by compressor *1*. Due to air jet circulation in the chamber, the hydroquinone particles were suspended in air and thrown out of the chamber through the second hole (in the center of the feeding chamber bottom), thus entering the object chamber *4*.

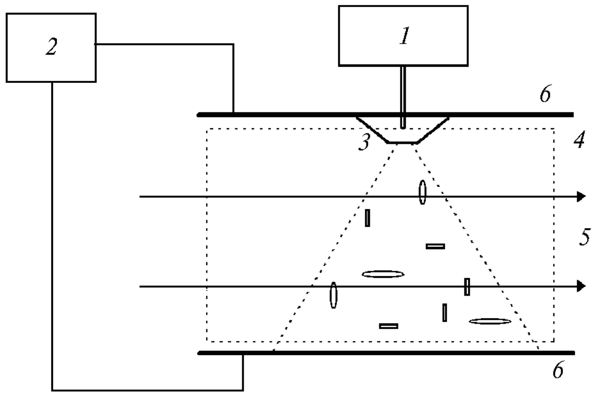

Fig. 2. Modeling of crystalline aerosol exposed to electric field: compressor *1*, power supply *2*, feeding chamber with crystals *3*, object chamber *4*, illuminating laser beam *5*, and electrode plates *6*.

Metal 35×35 cm electrode plates *6* for generation of the homogeneous electric field in the chamber were placed on two opposite (horizontal or vertical, depending on a studied situation) outer walls of the object chamber.

Thus, a depositing ensemble of model crystals was created in the object chamber. The model crystals were under the effect of gravitation, aerodynamic, and, if necessary, electric field forces. This allowed us to model various types of behavior of aerosol crystals in the atmosphere.

Experiment

In the experiment, we studied the model crystalline aerosol under different conditions (various pressures in the feed chamber, various orientations and strengths of the electric field). The used power supply unit allowed the electric field strength to vary from 0 to 8 kV/m.

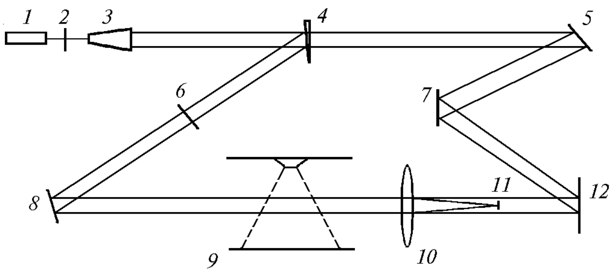

Fig. 3. Optical layout of hologram recording: laser *1*, neutral light filters *2* and *6*, collimator *3*, beam splitter *4*, mirrors *5*, *7*, and *8*, object chamber *9*, objective *10*, opaque mask *11*, and photographic plate *12*.

The optical layout of the laboratory setup is shown in Fig. 3. For hologram recording, we used a ruby laser of an UIG-12 device operating in the mode of passive Q-modulation (λ = 0.69 μm, pulse duration $\tau_{0.5}$ = 50 ns, energy per pulse no less than 150 mJ). The off-axis scheme with image transfer[7] was employed. The beam diameter after collimator *3* was 25 mm. To provide the linear mode of hologram recording, the intensity ratio of the reference and object beams was adjusted with neutral light filters *6*. Having passed through the object chamber containing the crystalline aerosol, the object beam came to objective *10* (Yupiter–37A, focal length of 135 mm) with opaque mask *11* set at its focus. Thus the volume image was transferred into the space behind recording photographic plate *12*, and the method of dark field was realized in order to enhance the contrast of holographic images of particles. Holograms were recorded onto Agfa Gevaert 10E75 halosilver photographic plates with the resolution no lower than 3000 mm^{-1}.

Holographic images were reconstructed with the use of the Spectra Physics He–Ne laser of 15 mW output power. The reconstructed image was observed in a MG–1 horizontal microscope. An ocular had reference lines allowing us to measure the angle Θ between the axis of the crystal projection onto the plane of the object beam cross section and the horizontal plane (zenith angle) accurate to 0.5°.

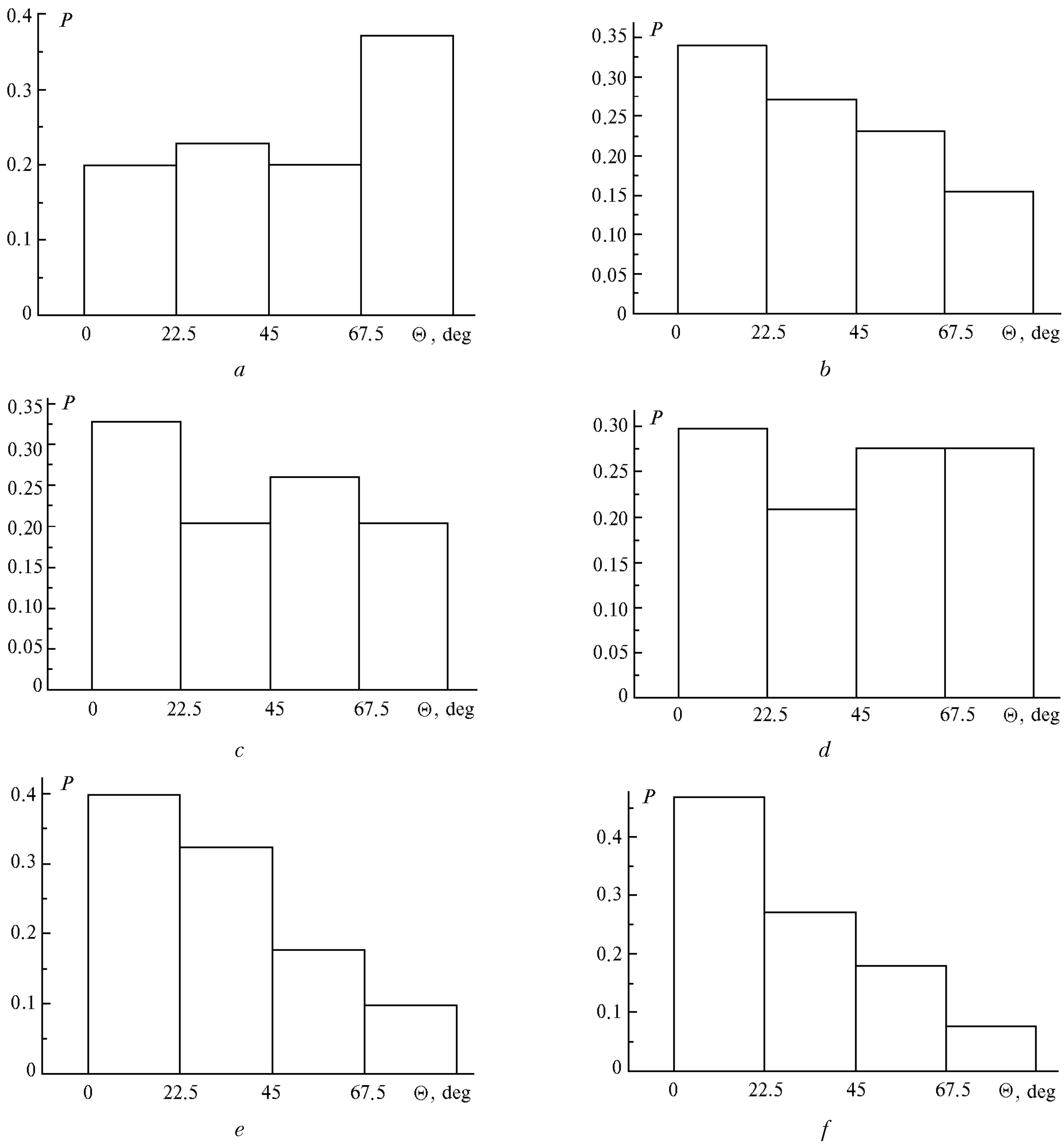

Fig. 4. Examples of histograms of orientation distribution of aerosol crystals (*P* is the part of particles whose axes are oriented within the corresponding range of the angles Θ.): in the absence of electric field (*a*, *b*) under the effect of air jet (*a*) and in free fall situation (*b*); at vertical orientation of electric field lines (*c*, *d*) at the field strength of 2.57 (*c*) and 4.29 kV/m (*d*); at horizontal orientation of the electric field lines (*e*, *f*) at the field strength of 5.14 (*e*) and 7.14 kV/m (*f*).

The laboratory setup was calibrated in resolution and magnification with the use of plane test microobjects produced by the method of photolithography and tested by means of holographic recording of water aerosol droplets by different schemes. We succeeded to obtain the resolution as high as 5 μm in the on-axis scheme and 10 μm in the scheme with image transfer.

Analysis of results

It is well-known that the horizontal orientation is dominant for column crystals in the case of free fall. To obtain these aerodynamic conditions in the experiment, we chose such pressure in the feed chamber, at which the part of crystals oriented along the air jet was minimal. Histograms of orientation distribution of aerosol crystals in the absence of electric field are shown in Figs. 4*a* and *b*. In Fig. 4*a* one can see some orientation of crystals along the air jet (the jet influence is noticeable); Fig. 4*b* corresponds to the case of free fall. Once the free fall conditions were achieved, the orientation of crystals under the effect of electric field could be studied.

Figures 4*c* and *d* shows the histograms characterizing orientation of crystals in the case that the electric field lines are oriented vertically (at the field strength of 2.57 and 4.29 kV/m, respectively). The obtained results allow us to note that the applied electric field changes the orientation of crystals, and this change is detected by the holographic method with an acceptable accuracy.

Besides, Figs. 4*c* and *d* illustrate the possibility of equiprobable orientation of crystal particles. Note that the physical modeling of such a situation is a complicated problem and is of interest by itself when studying radiation propagation.

As the electric field lines are oriented horizontally, crystals are markedly oriented along the field lines (Figs. 4*e* and *f*). In this case the field strength is 5.14 and 7.14 kV/m, respectively. One can readily see in the figures that the part of oriented crystals increases with increasing field strength.

Thus, a change of the electric field strength at the horizontal orientation of field lines increases the number of crystals oriented along the field as compared to the case of vertical orientation. This is explained by aerodynamic tendency of crystals to horizontal orientation.

Conclusion

It is shown in this paper that the holographic method allows the orientation characteristics of atmospheric crystalline aerosols to be studied remotely. The resolution of the method is sufficient for studying crystals in the size range corresponding to crystalline clouds.

A unique method of modeling the crystalline aerosol with controllable orientation of crystals is proposed. It is shown that one can obtain the needed degree of crystal orientation by varying the pressure in the object chamber, electric field strength, and orientation of field lines.

For simultaneous determination of the zenith and azimuthal angles of orientation of crystal axes in space, the two-channel scheme of hologram recording should be used.

Acknowledgments

This work was partially supported by the Russian Foundation for Basic Research (Grant No. R98–02–03031).

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