The influence of the electric field on the ice-forming properties of the reagent in the implementation of various mechanisms of crystallization

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Abstract. The features of the formation of ice crystals on reagent particles in a cloudy medium in the presence and absence of an electric field have been studied in the work. A complex of equipment from the laboratory of cloud microphysics of the High-mountain Geophysical Institute, which includes a sublimation chamber, a small cloud chamber, and an installation for bubbling reagent particles, was used. As a result of the experiments, it was found that when the condensation-crystallization mechanism is implemented, the specific yield of ice-forming nuclei in the cloud chamber decreases with increasing electric field intensity. When implementing the immersion mechanism, the electric field does not affect the specific output of ice-forming nuclei. In the case of a contact mechanism, the specific output of ice-forming nuclei is 2–3 orders of magnitude smaller than with the realization of the condensation-crystallization and immersion mechanisms.

Introduction
Studies of the processes affecting the formation of the microstructure of clouds show that the growth of ice particles from the vapor phase depends on the electric field strength, the charge of the crystallizing nucleus and on the realization of one or another growth mechanism.

The results of studies in [1-3] show that one of the ways to increase the rate of formation of a stable ice nucleus is the presence of an electric field.

Interesting results on the crystallization of water were obtained in [4]. The authors showed that at a high electric field intensity, a thin film of water crystallizes is present at room temperature.

To study the effect of the electric field on the formation of ice crystals on the reagent particles, experiments were performed in the laboratory of cloud microphysics at the High-mountain Geophysical Institute.

Materials and methods
A set of equipment was used for the experiments, consisting of a chamber for the sublimation of the reagent, a high-voltage unit, an analytical weighing – machine for weighing the reagent, and a video camera [5].

The chamber for the sublimation of the reagent is a rectangular tank with a volume of 1 m³ with heat-insulated walls. A fan is used to mix the reagent in the chamber; to clean the chamber from the remnants of the reagent - exhaust fan. The filter window creates an obstacle for room aerosols to enter the sublimation chamber. A sealed tube is used for sampling the reagent (Figure 1).
Figure 1. Reagent sublimation chamber: 1 – chamber walls, 2 – plates made of foiled getinax, 3 – fan for mixing air, 4 – tube for taking the reagent, 5 – aspirator, 6 – exhaust, 7 – window-filter

To study the effect of the electric field on the specific output of ice-forming nuclei in the implementation of the condensation-crystallization mechanism, experiments were carried out according to the standard procedure. AgI reagent was burned in the sublimation chamber with further transfer of the dispersed aerosol to the small cloud chamber [6].

Figure 2. Small cloud chamber: 1 – plane capacitor, 2 – steam generator

A steam generator is included in the installation kit to create steam (Fig. 2), which is a sealed cylinder capable of withstanding pressures up to 50 atm. The steam generator has a heating element, the generator is equipped with a pressure gauge for pressure control, a valve and an electric valve for launching steam into the chamber.

The electric field intensity was created by two parallel plates of foiled getinax installed in a small cloud chamber, to which a voltage of 8 kV was applied; the distance between the plates is 0.2 m. The electric field intensity was maintained at about \(4 \times 10^4\) V/m.
To take samples of the crystals, special substrates are placed in the chamber, which are metal disks of $d = 4 \text{ cm}$, covered with clean glasses. The glasses are covered with lids, which open when crystals appear. After the crystals are deposited, the glasses are transferred under the microscope and the number of crystals is counted. The specific output of crystals in the small cloud chamber, after the launch of the reagent, is determined by the formula:

$$A = \frac{n_{cr}}{m_r},$$

(1)

where $n_{cr}$ - the number of crystals in a small cloud chamber, $m^3$; $m_r$ - the mass of the injected reagent, g.

The mass of the injected reagent $m$ is determined depending on the mass of the reagent burned in the sublimation chamber. After burning the reagent, a certain volume of air is taken with the reagent and injected into the small chamber. The mass of the introduced reagent is determined from the ratio of the volumes of the large chamber and the volume of the introduced reagent.

$$m_{\text{reag}} = \frac{V_{\text{in.r}} \cdot M}{V_{\text{s.c.}}},$$

(2)

where $V_{\text{in.r.}}$ - the mass of the reagent injected into the small cloud chamber, g; $M$ - the mass of the burned reagent, g; $V_{\text{s.c.}}$ - the volume of the sublimation chamber, $m^3$.

Based on the number of crystals deposited on the substrate, the number of crystals in the small chamber will be determined:

$$n_{cr} = \frac{S_{\text{s.c.}}}{S_{\text{fr}}} \cdot n_{\text{sub}},$$

(3)

where $S_{\text{s.c.}}$ - the area of the reagent introduction chamber, $\text{mm}^2$; $S_{\text{fr}}$ - the area of the frame on the microscope, $\text{mm}^2$; $n_{\text{sub}}$ - the number of crystals on the substrate, $\text{m}^3$.

**Results**

According to experimental data, the dependences of the specific output of crystals on temperature in the presence and absence of an electric field were constructed (Figure 3).

![Figure 3. Dependence of the specific output of crystals on temperature with and without electric field](image)

*Figure 3. Dependence of the specific output of crystals on temperature with and without electric field*
The figure 3 shows that in both cases, as the temperature increases, the specific output of the crystals decreases at approximately the same rate: as the temperature increases by 1°C, the specific output of the crystals decreases by $6 \times 10^{10}$.

The equation of the specific output of ice-forming nuclei as a function of temperature in the presence of an electric field is:

$$A_1 = -6.0t - 27.7$$  \hspace{1cm} (4)

In the absence of an electric field:

$$A_2 = -6.3t - 12.8$$  \hspace{1cm} (5)

where $A_1$ - the specific output of ice-forming nuclei in the presence of an electric field, g m$^{-3}$; $A_2$ - specific output of ice-forming nuclei in the absence of an electric field; $t$ - the temperature in the cloud chamber, °C.

Analysis of the above data shows that with an electric field intensity of $10^3$ to $3 \times 10^4$ V/m, the specific output of ice-forming nuclei decreases, at temperatures of about $-6$ °C, 3 times, and 1.5 times at temperatures of $-10$ °C. With active influences on hail processes, the reagent is injected at a temperature level of $-6$ °C, the presence of an electric field at this level will reduce the concentration of the reagent three times.

Experiments to determine the effect of the electric field on the ice-forming properties of the reagent during the implementation of the immersion mechanism were also carried out in a small cloud chamber. AgI reagent was burned in the sublimation chamber, then the air with reagent particles was pumped (bubbled) through a tank with distilled water, as a result of which the reagent particles remained in water. Thus prepared water was sprayed in the small cloud chamber using a dropper dispersing unit [4]. The bubbling rate was one liter per minute. The electric field intensity remained the same as in the previous experiment.

The consumption of the reagent was determined depending on the mass of the burned reagent, the time of bubbling through the water and the volume of the reagent solution introduced into the small cloud chamber. The results of experiments to determine the specific output of reagent particles in the presence and absence of an electric field are shown in Table 1 and in Figure 4.

**Table 1.** Specific output of crystals in the presence and absence of an electric field as a result of the immersion mechanism implementation

| Without electric field | With electric field |
|------------------------|---------------------|
| t, [°C] | Specific output, 10$^{11}$ [g$^{-3}$] | t, [°C] | Specific output, 10$^{11}$ [g$^{-3}$] | t, [°C] | Specific output, 10$^{11}$ [g$^{-3}$] |
| 1 | 2 | 3 | 4 | 5 | 6 |
| -8.1 | 1.9 | -11.3 | 2.2 | -12.4 | 19.4 |
| -9.3 | 6.0 | -8.0 | 4.8 | -13.7 | 11.0 |
| -6.0 | 12.0 | -7.7 | 15.3 | -12.3 | 19.6 |
| -10.2 | 11.0 | -9.3 | 15.1 | -16.1 | 14.6 |
| -8.3 | 7.1 | -7.0 | 4.5 | -15.0 | 11.7 |
| -10.3 | 8.6 | -6.8 | 15.6 | -13.3 | 7.8 |
| -8.3 | 4.6 | -7.5 | 3.2 | -14.1 | 5.8 |
| -9.0 | 12.3 | -7.8 | 9.0 | -13.2 | 8.2 |
| -9.4 | 11.1 | -9.0 | 14.8 | -13.6 | 1.8 |
| -8.4 | 21.3 | -7.6 | 20.2 | -13.1 | 5.9 |
| -7.0 | 16.8 | -15.5 | 13.7 | -16.0 | 21.1 |
| -4.9 | 13.0 | -13.5 | 17.5 | -14.8 | 12.9 |
| -7.8 | 15.6 | -16.7 | 13.9 | -13.7 | 17.9 |
| -15.5 | 5.4 | -13.2 | 6.9 | -13.2 | 1.41 |
| -14.5 | 15.1 | -13.4 | 17.7 | -13.1 | 11.8 |
| -17.1 | 9.0 | -11.9 | 20.0 | -12.1 | 6.6 |
As can be seen from the figure 4 when the immersion mechanism is implemented, the electric field strength up to $4 \times 10^4$ V/m does not affect the formation of ice crystals on the reagent particles.

To implement the contact crystallization mechanism, the reagent under investigation was placed in a basket-helix made of nichrome, located in the reagent's sublimation chamber and burned. At the bottom of the sublimation chamber, glass substrates were installed on which the reagent was deposited.

Then the substrate with the precipitated particles of the reagent was transferred to the small cloud chamber, where the relative humidity was adjusted to 100% using a steam generator. After that, drops were sprayed in the chamber with the help of a device for dispersing. Drops by gravity deposited on glass substrates with particles of the reagent and crystallized. According to this scheme the contact crystallization mechanism was implemented.

Ice crystals were calculated using an automated system and the crystal specific output was determined [4].

The results of the experiments are shown in table 2.

As can be seen from table 2, in the case of a contact mechanism, the specific output of ice-forming nuclei is 2-3 orders of magnitude less than with the implementation of other mechanisms.

### Table 2. Specific output of crystals in the presence and absence of an electric field as a result of the implementation of the contact mechanism

|                      | Without electric field |                      | With electric field |
|----------------------|------------------------|----------------------|---------------------|
| $T$, [°C]            | Specific output, $10^8$ [g^{-1}] | $T$, [°C]            | Specific output, $10^8$ [g^{-1}] |
| -14.1                | 1.5                    | -11.9               | 22.3               |
| -12.6                | 10.0                   | -12.0               | 0.4                |
| -12.8                | 12.8                   | -11.7               | 1.8                |

**Figure 4.** Dependence of crystal specific output on temperature in the presence and absence of an electric field as a result of the immersion mechanism implementation.
Summary
As a result of the experiments the following results were obtained:
- the specific output of ice-forming nuclei in the cloud chamber during the implementation of the condensation-crystallization mechanism decreases with increasing electric field intensity. At the same time the enlightenment of the cloud environment between the plates with the electric field intensity occurs 10-20 seconds faster than without an electric field;
- the electric field during the implementation of the immersion mechanism does not affect the specific output of ice-forming nuclei in the cloud chamber;
- with the contact mechanism the specific output of ice-forming nuclei is 2-3 orders of magnitude less than with the implementation of the mechanisms.

References
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