The preliminary results of measuring specific charge on the particles of reagent forming by sublimation of AD-1 pyrotechnical composition

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Abstract: This article presents the results of laboratory experiments on testing of equipment and methods for determining the specific charge on reagent particles formed during the sublimation of the AgI and the AD-1 pyrocomposition. The method for measuring charged particles is based on the use of the deflection of reagent particles in the electric field of a flat capacitor. Preliminary results obtained in the course of research made it possible to establish that when pyrotechnic compositions are sublimated in the electric field of a flat capacitor with polarity «0», «+», the reagent particles are charged negatively, and when using a capacitor with polarities «0», «-» the particles of the reagent are charged positively. When using a bipolar capacitor, the particles are charged both positively and negatively, the ratio between negative and positively charged particles is 7:3.

1. Introduction
Studies of the effect of the electric field on the properties of the ice-forming reagent, show that the growth of nucleus particles depends on the electric field strength, charge crystallizing nucleus and on the implementation of a growth mechanism [1, 2]. Moreover, nanosized particles, like reagent particles, depending on their shape, can amplify the electric field near their surface thousands of times, which can lead to a significant increase in the temperature threshold for the formation of an ice phase on reagent particles.

The presence of an electric field and a charge on the reagent particles in the atmosphere can effect on the specific yield of ice-forming nuclei during work on weather modification [3-6].

In this regard, studies related to the study of the effect of the charge and shape of the reagent particles on the formation of the ice phase in clouds in the presence of an electric field are relevant and practically significant for determining the dosage of reagents when exposed on cloud processes.

2. Equipment for determining the charge on the particles based on a bipolar rectifier
The interest in laboratory studies of methods for increasing the effectiveness of weather modification has not diminished over the years. One of the directions of experimental research is the study of the influence of the electrical characteristics of the cloud medium on the formation of the ice phase on the reagent particles.

This article discusses the issues of determining the charge on AgI particles, which are formed during the sublimation of pyrotechnical compositions. The equipment and technique for measuring the
specific charge on the reagent particles formed during the sublimation of pyrotechnic compositions should provide:

- the ability to separate the reagent particle from other particles formed during sublimation;
- the preservation of particles with a charge for the study of their ice-forming properties.

The results of the analysis of works published on this topic show that none of them fully considered the issues of methods and special equipment for measuring the specific charge on reagent particles formed during the sublimation of pyrotechnic compositions [7-10].

A complex of equipment was created to study the formation of a charge on reagent particles. This complex includes a device for measuring the charge on reagent particles, consisting of three blocks: a sublimation unit for pyrocompositions and reagents, a trap unit, a turbulence damping unit, the Grad-3 system, thermal anemometer, scales, microscope, high-voltage rectifier, video camera (figure 1).

**Figure 1.** A complex of equipment for determining the specific charge on reagent particles.

The device for the sublimation of the pyrotechnic composition is a container in the form of a truncated cone, inside which a rectangular metal evaporation boat is installed. This metal boat covered with a plate of mica, from which the pyrotechnic composition is sublimated. During sublimation, a voltage of 9 V is applied to the metal boat, which the boat heats and sublimates the pyrotechnic composition. On the lid of the tank of the sublimation unit, there is a hole with 0.4 cm wide and 4 cm long, through which sublimation particles enter the trap unit. The trap unit consists of a transparent plastic tube, in which plates of FR-2 synthetic resin bonded paper with a size of 19×8 cm are placed; high voltage is applied to the plates.

To reduce the errors in determining the specific charge associated with flow turbulence, a turbulence damping unit is installed above the trap block. The turbulence damping unit consists of a plastic cylinder with a diameter of 100 mm and a length of 200 mm. Pipes with a diameter of 4-6 mm are vertically installed inside the cylinder. The upper and lower planes of the cylinder are covered with a metal mesh with cells of 0.4-0.5 mm. A fan is installed at the top of the unit to create an air flow. The flow rate in the trap block is determined using a Testo-425 anemometer.

To separate AgI particles from the entire set of particles that are formed during the sublimation of the AD-1 pyrotechnic composition, millipore filters were fixed on each plate to precipitate particles of sublimation products. The filters were manifested on the instrument table of the Grad-3 thermoelectric diffusion chamber, which has two independently operating thermostated metal surfaces, on one of
which the object under study is located, and on the other is a source of water vapor. The design of the stage allows processing filters of different sizes (from 23 to 55 mm).

The Grad-3 chamber provides automatic maintenance of a constant temperature of the stage and the source of water vapor in the range from +40 °C to -25 °C. The control is carried out by copper-constantan thermocouples, and the indication is carried out by a digital recording device. An Adventurer electronic balance was used to weigh the reagent.

3. Method for determining the charge on particles

The pyrocomposition is pre-weighing on an electronic balance and loading onto a metal boat to sublime the reagent. Then the fan of the turbulence damping unit is switched on and the air flow rate is measured using an anemometer. Sublimation of the composition begins after a voltage of 9 V is applied to the metal evaporation boat of the reagent sublimation device.

The sublimation product flow passes through a block of traps, in which it is partially deflected and deposited on the condenser plates. The process of sublimation of the pyrotechnic composition is recorded by a video camera. The degree of deflection of particles in an electric field is judged by video recording data.

Consider the movement of a charged particle in the electric field of a flat capacitor. Suppose that a particle with charge \( q \) and mass \( m \) moves with speed \( v \) in the electric field \( E \) of a flat capacitor. The particle is acted upon by an electric field with a force \( F = qE \), under the action of this force, a particle with mass \( m \) moves with acceleration \( a \), then we can write:

\[
F = am \quad \text{or} \quad q/m = a/E.
\]  
(1)

The path \( x \) traversed by the particle perpendicular to the flux is:

\[
x = at^2/2,
\]  
(2)

Motion time of particles \( t \) before collision

\[
t = y/v,
\]  
(3)

where \( v \) – particle movement velocity, \( y \) – path traversed by the particle from the bottom of capacitor plate to the collision with the plate along the plates.

Let us designate the specific charge as \( Q = q/m \). From formulas (1), (2), (3), after simple transformations, we obtain the formula for calculating the specific charge \( Q \) on particles:

\[
Q = 2xy^2/y^2E.
\]  
(4)

The experiments were carried out using three types of rectifiers: two unipolar ones with polarity «0» and «+», «0» and «-» and a bipolar rectifier.

4. Processes of charge formation on particles

As a result of numerical calculations, it was established [11] that the amount of charge can be calculated as the sum of charges calculated by the formulas of «contact» and «diffusion» charging. Let us denote the specific charge acquired by a particle during sublimation through \( q \), the specific charge acquired through the diffusion mechanism through \( q_d \), the specific charge acquired through the contact mechanism through \( q_c \), the specific charge acquired through the diffusion and contact mechanisms, through \( q = q_d + q_c \) when using a unipolar source with poles «0», «-» and \( q = q_d + q_c \) when using a unipolar source with poles «0», «+».
The total specific charge $Q$ acquired by a particle consists of the sum of the specific charge $q$ acquired by the particle during sublimation and the specific charge acquired due to diffusion and contact mechanisms ($q_-$ or $q_+$). Considering that the mobility of negative air ions is 1.4 times greater than positive ions, i.e. $|q_-| = 1.4|q_+|$ [4], we obtain for a particle with a negative specific charge:

$$Q_1 = -q - 1.4q_+,$$
$$Q_2 = -q + q_+,$$

(5)

for a particle with a positive specific charge:

$$Q_1 = q - 1.4q_+,$$
$$Q_2 = q + q_+,$$

(6)

where $Q_1, Q_2$ is the total specific charge of the sublimation particle when using a unipolar source with poles «0», «+» and «-», «+», respectively. When using a bipolar rectifier, if the specific charge of the particle is negative

$$Q_{2P} = -q - 0.4q_+,$$

(7)

if the specific charge of the particle is positive:

$$Q_{2P} = q - 0.4q_+.$$

(8)

From (5) and (6) we obtain expressions for determining the negative and positive specific charges of sublimation particles when using two unipolar rectifiers:

$$q = -\left(Q_1 + 1.4Q_2\right)/2.4,$$

(9)

$$q = \left(Q_1 + 1.4Q_2\right)/2.4.$$

(10)

Specific charges $Q_1$, $Q_2$ and $Q_{2P}$ for sublimation products are determined based on the deflection of a particle in an electric field from photograph. To determine the specific charges of the reagent particles, the products of the sublimation of the pyrotechnic composition are deposited on filters. Then the filters are kept at a temperature of $-15 \, ^\circ C$ in the Grad-3 system. Ice crystals form on the reagent particles and the results are analyzed. This approach makes it possible to distinguish AgI particles from a set of other particles. The specific charge type can be determined by the degree of deflection of the particle flux. If the angle of deflection when using the rectifier «0», «+» is greater than for the rectifier «0», «-», then the particles are charged negatively during sublimation, in the other case, positively. When using a bipolar rectifier:

- if the particles are negatively charged during sublimation, then the recharging of the particles does not occur;
- if sublimation particles are positively charged, recharging can occur under the condition $q < 0.4q_+$.

5. Results

A series of preliminary experiments on testing the equipment and methods for determining the specific charge on the reagent particles formed during the sublimation of the AgI reagent and the AD-1 pyrocomposition showed that the deviation of the reagent particle flux in the electric field of a bipolar rectifier occurred towards the positively charged plate. Figure 3 shows a video fragment showing that AgI particles are charged negatively during sublimation. In [12], when using a unipolar rectifier with polarity «0», «+», it was found that AgI particles are positively charged during sublimation.
Differences in results are due to the use of different rectifiers. When using a unipolar rectifier to
determine the specific charge of particles, the effect on the specific charge of particles of the device
itself must be taken into account. The experiments show that when using unipolar rectifiers, the
particles have time to recharge and acquire a capacitor charge, if the rectifier has polarity «0», «+»,
then positive, if «0», «-» then negative. Figure 2 shows a photograph of the deflection of sublimation
particles in an electric field created by unipolar rectifiers with poles «0» and «+» (a) and with poles
«0» and «-» (b).

When using a rectifier with «0» and «+» poles (figure 3a), the total specific charge is positive, and
when using a rectifier with «0» and «-» polarities (figure 3b), the total specific charge is negative.
This is because during the movement of the sublimation particle in the electric field of a unipolar
capacitor with polarity «0» and «+» or «0» and «-», the particles have time to recharge.

![Figure 2](image2.png)

**Figure 2.** Deflection of reagent particles in an electric field.

![Figure 3](image3.png)

**Figure 3.** Deviation of the particle flux from the AD-1 pyrocomposition in the electric field of a
unipolar rectifier with polarity «0», «-» (a), with polarity «0» and «+» (b).

Table 1 and figure 3 show the distributions of charged particles by specific charges. As shown in
table 1 and the above values, there is a significant difference in the results obtained, which, apparently,
is due to the underestimation of the mobility of positively and negatively charged ions. This problem is the subject of further research.

**Table 1.** The distribution of reagent particles formed during the sublimation of the AD-1 pyrocomposition by specific charges.

| Specific charge $(q/m)$, C/kg | Share of negatively charged particles, $n_-/N$, % | Share of positively charged particles, $n_+/N$, % |
|-------------------------------|-----------------------------------------------|-----------------------------------------------|
| $145 \cdot 10^{-4}$          | 29                                            | 12                                            |
| $16 \cdot 10^{-4}$           | 22                                            | 10                                            |
| $5.8 \cdot 10^{-4}$          | 19                                            | 8                                             |

**Figure 4.** The share of charged particles of the reagent formed during the sublimation of the AD-1 pyrocomposition ($n/N$), at different values of the specific charge $(q/m)$.

**6. Summary**

The creation of equipment and the development of a technique for studying the charge on reagent particles from pyrotechnic compositions, based on the use of rectifiers of different polarity, made it possible to establish that when the reagent particles from the AD-1 pyrotechnic composition move in an electric field with polarity «0», «+», the reagent particles are charged negatively, and when using a capacitor with polarities «0», «-», the particles of the reagent are charged positively.

When the reagent particles move in the electric field of a bipolar capacitor, the particles are charged both positively and negatively, the ratio between negative and positively charged particles is 7:3.

When the reagent particles moving in an electric field, they acquire an additional charge, which may exceed the initial one.

Preliminary results of research showed that the specific charge during the sublimation of the pyrotechnic composition varies from 0 to 0.0145 C/kg.

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