

Thermoionic Method of Lightning Activity Reduction

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INTRODUCTION

Storm electricity – is a natural hazard for human and technical resources, leading to a large number of registered deaths, fires, damage and malfunction of technical devices. At some given period of time in the world there may occur over a thousand thunderstorms with an intensity of up to 50 lightning strikes per second. The mechanism of formation of thunderstorms is the subject of study to date. Formation of electrical structure of convective clouds is due to many factors, some remain unexplored. Phase and structural transitions of water in the atmosphere can be both cause and consequence of cloud electricity [1]. The main reasons leading to the formation of lightning discharges are spatial charges of electricity generated in the cloud. The article suggests a possibility of thunderstorm prevention and artificial discharge cloud electricity with thermionic method.

CLOUD ELECTRICITY FORMATION

To understand the process of formation of electrical charges in the convective cloud it is necessary to turn to the nucleation theory to explain the transition of water vapor to the liquid state (water droplets), and from a liquid to a solid state (ice crystals). It is also important to point out that the classical nucleation theory was developed in 30-40s of the twentieth century [2] and is being refined to date [3]. Calculations of drop growth on atmospheric condensation nuclei made in the middle of the previous century [4] showed that the droplets grow to 1-2 micrometers in a split second. By this time they become drops of pure water. Further growth is explained by water vapor supersaturation in the cloud and the accession of new hygroscopic condensation nuclei, however this process is very slow. Time of drops growth to a radius of 15 micrometers may last from 50 min [4], up to 7.5 hours [5]. Consequently, in convective cloud cells the lifetime of which is on average 30-40 minutes, formation of cloud droplets of radius 18 micrometers or more can not be explained only by condensation of water vapor [6].

Due to the fact that the stability of the colloidal system in liquids is determined by its electrical properties [6], it has been suggested that the droplets of colloid- stable clouds are charged with like charges, so that they repel each other and don't merge. This assumption is confirmed by the presence of positive charges in the cloud at the initial stage of its development. When drops are neutral or their charges are low, the process of drop consolidation begins.

The need to consider the effects of electrical forces on the process of integration of cloud droplets in the convective cloud arose to explain the mechanism of formation of bulk precipitation and spatial electric charges in the clouds. In the atmosphere, there are always ions produced by cosmic rays, evaporation of water from vegetation, the earth's surface radiation and other factors. [8] Charged particles in the atmosphere play a significant role in the process of precipitation formation in vivo. The problem of the influence of electric forces on condensation-coagulation processes in different years were considered by B.J. Mason [4], V.M. Muchnik [6], L.M. Levin [9], N.S. Shishkin [11], N.V. Krasnohorská [10], I.M. Imyaninov [12] and other researchers. It has been found that a variety of electrification mechanisms has a varied significance in the different periods of cloud growth and under different conditions.

Measurements of charge cloud particles directly in the clouds showed that 90 % of all drops are charged [12]. Formation of electric charges on cloud particles is caused by ion

adsorption processes, phase transitions of water, destruction of particles and other factors. Based on the experimental study of the effectiveness of the collision of uncharged droplets similar in size, it can be assumed that most collisions are elastic and do not lead to a merger [6]. The presence of electric charge, reducing the surface tension facilitates the formation of the connecting channel between the droplets. Formation of connecting channel occurs at a potential supplied to the drop is less than 10 V. Such potentials correspond to the charges cloud and rain drops. Charge of small cloud droplets is less than $3 \cdot 10^{-14}$ C; charges of large drops in average $10^{-12} - 10^{-11}$ C [13]. For drops of a radius of 10 micrometers charge limit is $\sim 3 \cdot 10^{-14}$ C.

According to the conclusion made by I.M. Imyanitov [12], the effectiveness of the merger of collided droplets depends on the electric field intensity and the magnitude of the charge on the droplets. Lab measurements indicate that the change in field strength from 0 to 15 V/cm increases merger efficiency of larger drops by more than three times. Field intensity in cumulus clouds reaches 1-5 V/cm or more [10 and others]. Convective cloud on stage Cu hum - Cu med is positively charged entirely [14], as the negative ions are involved in the formation of cloud droplets and positive ions rise upstream to the top of the cloud. At a Cu cong stage a positive charge is observed at the top of a cloud and at the bottom - negative [12,13,14]. Appearance in the convective cloud of opposite charges indicates the beginning of the formation of electric energy of instability.

I.M. Imyanitov was the first to consider the energy of instability of the electric origin. He believed that, along with the thermodynamic energy, phase and colloidal instability in the clouds, under certain circumstances, there can appear the energy of instability of electric origin [1]. I.M. Imyanitov did not indicate in which processes this energy may develop, however, he saw opportunities for effective intervention in the atmospheric electric processes with relatively low energy available to people.

It seems logical to present the energy of instability of electric origin as two different kinds: energy instability of the first kind, which appears when the ion, electron or Rayleigh limit (hereinafter the Rayleigh limit [18]) is reached; and the second kind, which manifests itself in lightning discharges in the accumulation of the limit the amount of electricity, which leads to lightning discharges in certain volumes of cumulonimbus clouds (hereinafter the Imyanitov limit). The process of accumulation and charge separation occurs in cumulonimbus clouds in ascending and descending jets and thermals as a result of consolidation, fragmentation and evaporation of cloud droplets and crystals. The average concentration of jets is 40 per 1 km² or 750 thermals 1 km³ according to research presented in [15].

Further we will consider one of the possible mechanisms of space charges formation which forms the basis of thermionic method of convective cloud electricity control.

ADSORPTION OF IONS BY CLOUD DROPS

It should be emphasized that the existing theory of intermolecular interactions involve small size of the interacting molecules compared with the distance between them (between their "centers"). Interaction potential between the contacting molecules can only be found by experimental methods [2]. Consequently, there is no single answer to the question of the fate of the ion, collided with a water surface of the drop. To answer this question, we must consider some research on physical adsorption. This is the physical adsorption, when there is no strong overlap of electron shells (sharing of electrons) of ions of different chemical elements with surface water molecules. Ions and molecules of water molecule in their intermolecular interaction retain their chemical identity.

When a gas molecule (ion) hits the surface of the drop, it remains on it for some time. The main factors determining the length of the molecule stay on the surface, are: the nature of the molecule and the surface, the surface temperature and the kinetic energy of the molecule [3]. Immersion of the ion inside the water drop is connected to the energy cost on overcoming the hydrogen bonds between water molecules. Hydrogen bond energy is estimated to be 1 eV. The

average thermal energy of the ion at $T = 300\text{ K}$ is about 0.4 eV . In addition, the electric interaction forces between the ion and the dipoles of water molecules provide additional resistance to overcome the water surface at ion adsorption on charged centers with the opposite sign. Hence, the system free ion - water surface moves to a lower energy level.

The essence of physical adsorption may be summarized by the saturation of the unbalanced forces on the adsorbent surface, which should lead to a decrease in surface tension [16]. In other words, the ion remains on the surface if its interaction with the water molecules is weaker than the interaction between the water molecules themselves. Given the wide range of thermal velocities of the ions and their interactions with water molecules, it is reasonable to assume that chemical composition and velocity of some ions, located on the surface of the drop for a long time, in cold temperatures will intensify ice embryo formation.

At the present level of development of science theoretical justification of the above interactions should be conducted within the framework of quantum-chemical approach. Example of calculation, as given in [3], shows the extreme complexity of these calculations, even with numerous simplifications that are very difficult (if at all possible) to prove.

It remains to use the experimental facts set forth in [17]. Briefly, these facts are as follows: some ions interact with water molecules stronger than these molecules interact with each other (positive hydration); for other ions - the opposite situation (negative hydration) takes place. Under this condition, the positive hydration with decreasing temperature may convert into the negative one. Positive ions of sodium, potassium, rubidium, cesium, i.e. chemical elements of Group 1 of the Periodic Table of Mendeleev, are characterized by negative hydration.

This idea of surface charge of water droplets is supported by some indirect factors: for example, setting the limit surface charge on the basis of the droplet surface brake off by electrostatic repulsion forces. According to Rayleigh's theory, the amount of charge is determined by equating the electrostatic field energy to twice the energy of the surface tension [18].

Calculations of interaction of electric charge of the drop with external charged particles generally involve either the spherical symmetry of the charge drops, or a significant excess of interaction distance above the linear dimension of the interacting particles. Thus, there is no specification of the form of charges (ions dissociated within the droplet or to some extent hydrated ions on the surface). Ions in the water as a dielectric environment with rigid polar molecules - dipoles must generate bound charge on the droplet surface.

Hydrated ions remaining on the surface of the drop, will represent the electrical system: the charge of the "pure" ion or electron and a multitude of dipoles around it, if hydrated ion cover (light ion) consists of a single layer of molecules; and bound charge on the surface of the hydration cover, if the cover is composed of several layers of molecules (heavy ion).

Ion adsorption by water droplets may be understood as breaking the potential barrier of the surface of the drop, the value of which is 0.25 V . It is believed that only positive ions need to have the corresponding energy to overcome this barrier; negative ions easily penetrate deep into the drop. Taking into account the above, such a representation of the ion interaction with surface water molecules is extremely simplistic. Charging of droplets is considered through their coagulation with ions. At the same time some assumptions are made: the electric fields of drops do not overlap due to the rather low concentrations; the time of establishment of the diffusion streams is significantly less than the time of charge accumulation for ion flow into droplets; at distances larger than the mean free path of ions Maxwellian velocity distribution is observed. As a result droplets are charged positively. During evaporation positive ions leave the droplet first, and the remaining amount to negative ions form the negative charge of the droplet. We would like to explain this process in more detail in an experimental model of cumulus clouds.

EXPERIMENTAL MODEL OF CONVECTIVE CLOUDS

The experimental model created by V.A. Zaitsev, based on experimental data of droplet structure of the convective cloud and generalized data on the distribution of water content, shows the size and number of droplets in the cumulus cloud, as presented in Figure 1 [7]. The cloud is divided into four zones, the largest drops are located in the central part of the cloud (zone III).

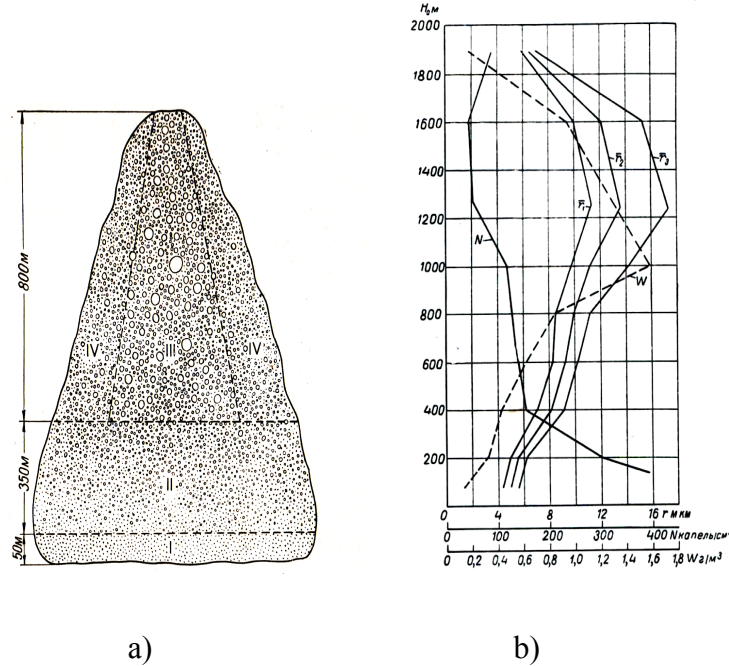


Figure 1: a) Schematic distribution of droplets in cumulus clouds ; b) The average distribution of water content (W), size (r), and the number of drops (N) in Cu cong capacity of 2000 m [7].

Zone I at cloud base ($\sim 50\text{m}$) relates to the level of condensation. In this zone the majority of the drops (65 %) has a size of 4 to 8 micrometers. Droplets formed in this area rise with the upstream, and in their place the formation of new droplets begins. In zone II ($\sim 50 - 400\text{m}$), the majority of droplets (60 %) has a size from 6 to 14 micrometers, the maximum diameter of the droplets is less than 50 micrometers. Zone III, which occupies the central part of the cloud, is located at height of 400 m above the cloud base to its top. In this zone, 60 % of all droplets have a diameter of from 8 to 18 micrometers, the largest droplet size of 100-300 micrometers, individual droplets reach 300-400 micrometers or more. The presence of large drops in the center of the convective clouds is indicative of the presence of the powerful upward air flows.

Zone IV is located at the edge of the convective cloud and has a thickness of 50-100 m, the predominant droplet 8-14 micrometers, no large droplets. Connection between the size (r) of cloud droplets growing is optimally reflect by the Hrgian - Mazin pattern of distribution of cloud droplets [10]:

$$n(r) = Ar^2 \exp(-br), \quad (1)$$

where $A = 1,45\delta r^{-6}\rho^{-1}$, $b = 3r^{-1}$, r - mean droplet radius, δ - conductivity, ρ - density of water.

Drops shown in Figure 1 in the zone III, have a size of 8-18 micrometers to 100 -400 micrometers in diameter. The bulk of cloud water in continental clouds contained in the droplets radius from 3-4 to 20-30 micrometers. The concentration of such droplets is $10^2 - 10^3 \text{ cm}^3$ [23]. Vertical motion inside the cloud has the character of individual jets and thermals. According to V.A.Zaytsev [7], the area of the ascending vertical velocity jets with $\sim 5\text{ m/s}$ in different clouds is 20-35 % of the total cross sectional area of the middle part of the cloud. Maximum upstream rate in Cu cong capacity of 3-4 km reaches up to 10 -11m / s. Downstreams in these clouds

occupy from 50 to 65 % of the area mainly in the periphery and have a cloud velocity of about 2 m / s, at the same observed are areas of up to 15%, where the vertical motion is practically zero. Downward movements are turbulent and observed with an average speed of about 2m / s. Range of temperature changes is also formed by the turbulent exchange. Empirical model of convective clouds will not be complete without taking into account a number of other factors - involving turbulence, electrical charges, etc. Downward movement in the cloud is simultaneous to the process of evaporation of positively charged ions from the surface of the drop, leading to the formation of a positively charged spatial charge.

The above theoretical points lead to practical conclusions. As shown on an example of V.A. Zaitsev experimental model of Cu cong, at the base of the cloud droplet number is about 400 in cm^3 , and at the altitude of 1000 m from the base of the cloud it reduces to 50 in cm^3 . The question arises about the fate of the remaining drops when updrafts in the cloud take place. In the result of the adsorption of atmospheric ions by small droplets the electrical instability of the first kind occurs, i.e. drops achieve the Rayleigh limit and their disintegration into positive and negative ions. Negative ions are adsorbed by not disintegrated larger drops, and positive ions are raised to the top of the cloud free or on the surface of the remaining drops, causing a positive charge at the top of the cloud. Negative ions are transported to the top of the cloud inside the cloud drops.

INFLUENCE OF ELECTRIC FORCES ON COAGULATION OF DROPS

Experimental studies conducted by different authors [11, 12, 21] have shown that the effect of electric forces on coagulation of drops can be substantial. Experiments on deposition of artificial fog with charged water droplets by N.A. Wager [21] revealed the existence of a positive effect. Artificial fog, persistent in the fog chamber for more than 2 hours, when exposed to small electrified water drops quickly changed its transparency. The density of negative charges of water droplets was about $\sim 2.5 \cdot 10^{-4} \text{ C / kg}$, and of positive charges $\sim 5 \cdot 10^{-4} \text{ C / kg}$. When considering the growth of cloud droplets in this size range, V.M. Muchnik [6] concluded that the charges of drops should be considered. The movement of particles in the cloud takes place under the influence of gravity, frictional force, the Coulomb force of the electrostatic interaction, force of the electric field of drop polarization by the electric field of the Earth, the force of attraction due to the induction of opposite charges.

Theoretical studies [9, 10] have shown that droplet charges affect their coagulation in the size range less than 30 micrometers. The calculations suggest that in the case of opposite charges droplet coagulation is enhanced by the strength of the electric interaction. In the presence of the charge on the bigger drop and the absence of it the smaller, coagulation is furthered by the formation of an induced charge on a smaller drop. In the collision of considerably large drops the role of electrical forces is greatly increased as a result the fusion of the droplets becomes more efficient.

Variety of mechanisms of electrification has a different significance in various periods of cloud growth and under certain conditions.

ELECTRICAL INSTABILITY OF CLOUD DROPLETS

If atmospheric aerosols are a mixture of positively and negatively charged ions, the water due to the bipolar molecules acquires its property of "universality", capturing both light and heavy particles of different sizes. Selective properties of water surface are associated with the electric double layer (EDL) on the water- atmosphere boundary. EDL is formed by the asymmetry of the water molecule consisting of two different atoms. As a result, in surface layer of liquid there exists a layer of oriented polar water molecules, and H_2O molecules on the water surface are oriented with negative poles outwards and positive poles inwards. According to the theory of Y.E. Frenkel [2], selective adsorption of ions by water surface is explained by easier

penetration of negative ions through the electric double layer than of the positive ones. This is due to the fact that under the influence of an electric field of oriented dipoles, positive poles of the water molecules in the drop are directed towards cavities. Negatively charged ions get on the water surface and begin to move into the liquid and positive ions remain on the surface and can also evaporate similarly to neutral water molecules. This explains the positive charge of convective clouds in the development stage. In the stage of stabilization negative charges appear, caused by downdrafts.

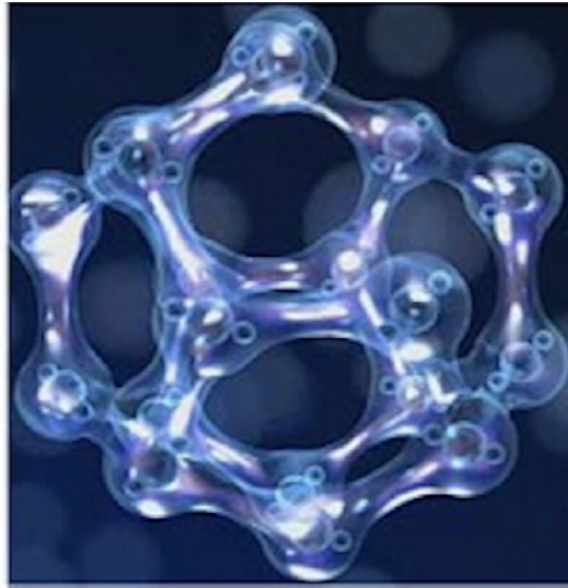


Figure 2 . A drop of water under the microscope [27].

As a result of differences in energy costs needed for breaking surface layer by ions of opposite charges on both sides of the water surface there emerge areas with opposite electric charges and of equal value, i.e. EDL develops on the surface. Theory of EDL structure proposed by Stern, summarizes two preexisting theories by Helmholtz - Perrin and Gouy - Chapman [11]. According to this theory, the fluid contains a number of ions of the same sign. In the adjacent air a portion of the ions of the opposite sign (counter ions) is located in the layer with the thickness δ (adsorption Helmholtz layer), and the other portion of counter ions forms a diffusion layer (Gouy layer), in which the ion concentration varies exponentially with distance from the surface of the water .

Potential in the adsorption layer decreases linearly, and in the diffusion layer exponentially. The thickness of the diffusion layer is the distance at which the potential decreases in e (2.718 ...) times. With decreasing temperature, the chaotic motion of the ions is slowing and the diffusion layer thickness decreases up to the adsorption layer thickness. Water surface captures only ions for which the kinetic energy is greater than the value of potential barrier A . At the boundaries of the EDL potential jump is -0.26 V, and the thickness is equal to $5 \cdot 10^{-9}$ m. Because of the selective properties of the water surface, at the same conductivity of positive and negative ions in the atmosphere, the water surface is charged negatively.

With respect to cloud drops it was shown that only in the case, when the conductivity of the positive ions is about twice the conductivity of the negative ion, charge of the water surface is equal to zero, the author of the paper [11] considered selective surface properties of drops for the diffusion mode of electrification. However, there is a tendency to increase the discrepancy between theory and experiment with decreasing particle size. A likely reason for this may be a mirror force.

In general the problem of defining expressions for EDL is associated with the description of three-dimensional random wander of ions in the environment with random ion sources (acts

of ionization) and random sinks (aerosol particles, heavy ions, drops, etc.). It is extremely difficult to construct such theoretical framework, so it is usually limited to the solution of simpler problems, based on the following assumptions:

- electrifying particles do not interact with each other;
- formation of the ion current on the particle is stationary;
- there are only singly charged ions.

The applicability of the first assumption is confirmed by numerous estimates. According to N.A. Fuchs [18], the time of restructuring of the concentration field of atmospheric ions (with the change of the charge electrifying particle) is less than the average time between acts of ions capture by the particle, so that stationary description of the behavior of ions is fairly right. Influence of the electric double layer on the charged particles is neutralized with excessive negative charge of water, which creates an electric field, equal in magnitude and opposite in direction to the electric field of the double layer. In balanced condition, the potential jump in EDL on the droplet surface is compensated by the electric field of the negative charge of the drop [18]:

$$\varphi = Q / 4\pi r \varepsilon_0, \quad (2)$$

where φ - potential drop in EDL ; ε_0 - permittivity of free space , r - droplet radius (m). Hence, the value of the equilibrium charge Q drops power (C):

$$Q = 4\pi r \varepsilon_0 \varphi \quad (3)$$

Ions are influenced by electrostatic force, F :

$$F = Qq / 4\pi r^2 \varepsilon_0 \quad (4)$$

In this case, the density of electric field is :

$$E = Q / 4\pi r^2 \varepsilon_0, \quad (5)$$

and the potential energy (W) of a positively charged ion is:

$$W = Qq / 4\pi r \varepsilon_0 \quad (6)$$

In accordance with the Boltzmann law, distribution of ions in the field around the drop is described by the formula:

$$N_{\pm}(r) = N_{\pm}(\infty) \exp(-Qq_{\pm} / 4\pi r \varepsilon_0 kT), \quad (7)$$

where $N_{\pm}(r)$ - the concentration of ions at the surface of the drop ; $N_{\pm}(\infty)$ - the concentration of ions away from the drop.

On the basis of these expressions the rate of change of the electric charge of the drop can be obtained by [2,18]:

$$dQ / d\tau = q_+ \pi r^2 V_+ N_+(\infty) \exp(-Qq_+ / 4\pi r \varepsilon_0 kT) \exp(-A / kT) + q_- \pi r^2 V_- N_-(\infty) \exp(-Qq_- / 4\pi r \varepsilon_0 kT) \quad (8)$$

where V_{\pm} - the average thermal velocity of the ions.

An expression for the equilibrium droplet charge $q_+ = q_-$ can be obtained when $dQ / d\tau = 0$:

$$Q = 2\pi r \varepsilon_0 kT / q_+ \{ \ln(V_+ N_+(\infty) / V_- N_-(\infty)) - A / kT \} \quad (9)$$

According to the formula (9) limit charges of drops in the cloud may be theoretically determined: the maximum positive charge of $Q^+ \max(r) = 4\pi r^2 \varepsilon_0 2 \cdot 10^{-10} C$ and maximum negative $Q^- \max = 4\pi r^2 \varepsilon_0 10^{-9} C$. If value Q exceeds the maximum charge of the drop, the energy of the electrostatic field of the charge of the drop will exceed its surface energy. In this case the drop will brake up due to the proximity of the same charges.

Upon absorption of ions and electrons, it was shown that for a given electric field density at a given particle size there is the maximum possible charge of the particle. However, the charge of the liquid drop can not reach the limit defined by the expression (10) , except when it does not exceed 100 micrometers in diameter. The maximum charge of the drops (in absolute value) at which their fragmentation occurs [18] is:

$$q_R(r) = \sqrt{64\pi^2 \varepsilon_0 \sigma_{IB} r^3} \quad (10)$$

where $q_R(r)$ - the maximum charge drops (in absolute value) of radius r , if it is exceeded the drop will brake up due to the proximity of the same charges the drop will brake

up due to the proximity of the same charges , C ; ε_0 - Permittivity of free space , equal to

$8.85418782 \cdot 10^{-12}$ F / m; σ_{IB} - The surface energy at the boundary of vapour - water at temperature T (at $0^\circ\text{C} = 7,61 \cdot 10^{-2}$ J/m²) .

For drops of different sizes the possible values of limit charges and Rayleigh limits given in Table 1.

Table 1. Limit on the number of elementary charges on the particle [18].

Limmit	Diameter of particles, micrometers		
	0,01	1,0	100
Ionic	$3,47 \cdot 10^2$	$3,47 \cdot 10^6$	$3,47 \cdot 10^{10}$
Electron	$1,72 \cdot 10$	$1,72 \cdot 10^5$	$1,72 \cdot 10^9$
Rayleigh limit	$4,45 \cdot 10$	$4,45 \cdot 10^4$	$4,45 \cdot 10^7$

The maximum number of ions and electrons for a drop with the diameter of 100 micrometers is $3.47 \cdot 10^{10}$ and $1.72 \cdot 10^9$ respectively. For comparison, a raindrop with the diameter of 10 micrometers in a thunderstorm is about $4 \cdot 10^8$ elementary charges, which is 1 % of limit charge [18]. In the evaporating droplets Rayleigh limit decreases with decreasing droplet size. Therefore, the diameter droplets which can evaporate will decrease up to 0.01 micrometers. Not vaporized droplets will be absorbed by larger drops, increasing their size. Large drops will fall down, but small droplets formed during the fragmentation in accordance with the achievement of the Rayleigh limit, will go to the formation of new large droplets. Chain process of space charge and precipitation will continue until the washing of cloud water. An impetus for artificial precipitation and conductivity change in the convective cloud is artificial thermoionization.

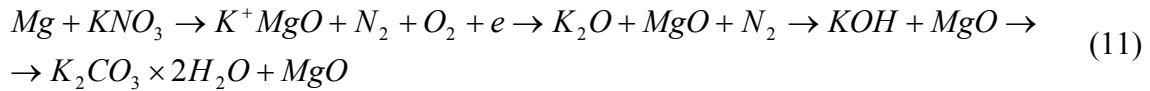
THERMIONIC METHOD OF ACTIVE INFLUENCE ON ELECTRICITY OF CLOUDS

According to modern understanding of the structure of the storm clouds, the concentration of charged particles with the values of the voltage reaching $10^5 - 10^6$ V / m occurs in small amounts, formed by upstream and downstream jets [6,11 et al.] To cause lightning to the ground or between cloud formations it is necessary to achieve the critical values of the field density and the creation of an electrically conductive channel for the flow of electric charge. Critical values of intensity for artificially triggered discharge may be 4-7 kV / m (the Imyanitov limit), the minimum length of artificially created channel should be 100-200 m , and the minimum concentration of electrons in it $10^7 - 10^8/\text{sm}^3$ [12].

The proposed method for triggering lightning is characterized by the fact that for the initiation of lightning discharges in the atmosphere an ionized channel is created in the form of a flux of charged particles using a thermionic method. It is known that the lightning discharge is preceded by the formation of the fast flowing process of forming long ionized channel, with a small cross section, which consists of electrons, and is called the "leader" [24]. Increase in air

conductivity in the convective cloud increases electrical losses in the cloud and lightning attenuation process. Observations show, that in the cloud with high conductivity the probability of a lightning discharge is noticeably reduced [12,22].

Development of artificial ionization sources to create an artificial ionized channel is based on pyrotechnic method of dispersing agent. Pyrotechnic composition (PC) for generating a charged aerosol prepared from a mixture of powdered metal fuel (magnesium or its alloys), oxidizer (nitrate, potassium or other alkali metal), and small additions of organic matter (urea, etc.) Russian patent number 2,090,548 [20]. Effective source of artificial ionization are solid aerosol particles generated during combustion of metal fuel of temperatures 3500-4000 K, which emit electrons by thermionic emission. This effect was first described by S. Sow [25]. Schematically, the combustion reaction occurring PC at about 3500-4000 K can be represented as follows [20]:



Pyrotechnic composition for use from the aircraft used in the models of upgraded squibs PV- 26 FHS in 40 mg capsule with center-fire or electric igniter. PC combustion in the atmosphere in such amount of reagent takes 16-18 s, the channel is formed by thermal ionization path of the PC is 800-900 m [26]. Main mechanism of ionization within the thermionic channel is thermal electron emission from the hot aerosol particles in a track of their source - burning PC. The total amount of electron emission is determined by the duration of the heat conservation of the produced particles, and it reaches the amount of 10^{18} for 1g of reagent. Loss of electrons by hot particles causes their positive charge. Electrons colliding with the surrounding air molecules (mainly oxygen) form negative ions. Attachment of electrons to oxygen molecules occurs in triple collisions:



where M - H_2O molecule or other gases.

Obtained by calculation the amount of positive ions with the size $10^{-7} - 10^{-5}$ cm is around 10^{13} g^{-1} , the amount of negative ions is 10^{18} g^{-1} [26].

Burning of the PC in the air at the combustion temperature of magnesium 3000-4000 K leads to the formation of solid aerosol particles, which represent different salts and oxides. Test results of PC in the fog chamber are shown in Fig. 3. Solid aerosol particles formed as a result of combustion of PC have sizes in diameter from 0.0075 to 0.75 micrometers.

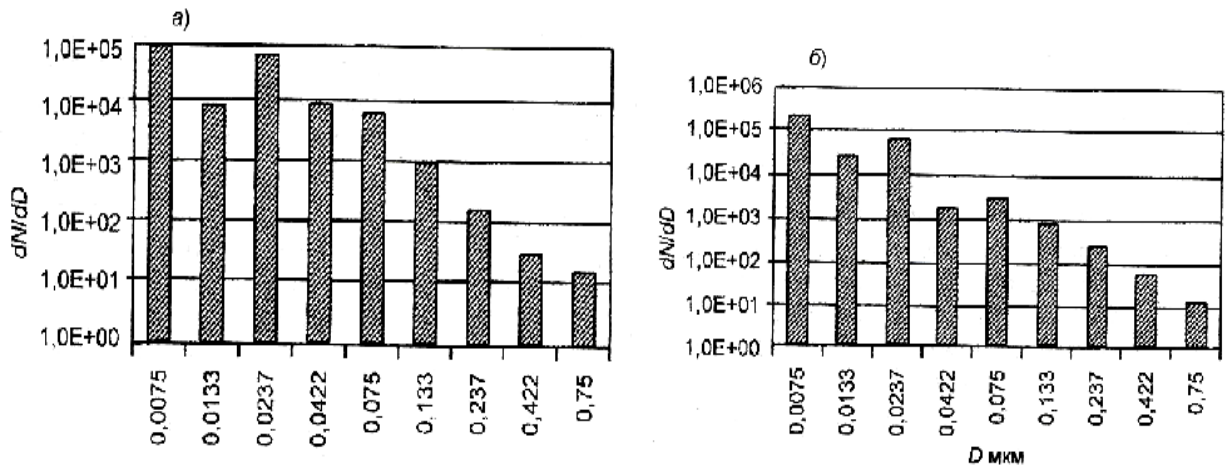


Figure 3. Distribution density of particles of burning PC according to the sizes at the time of generation (a) and after 30 min interval (b).

Calculated is the duration of the limit maximum temperature conservation along the trajectory of the source, depending on its speed and eddy diffusivity (k) coefficient according Richardson [29]. On the basis of the Maxwell velocity distribution, a precise calculation of the amount of electron emission from hot particles has been made. The electric field of the positive charge prevents the removal of emission electrons from the surface of emitting particles, bringing them back to the particle. Only electrons with energies higher than their interaction with the positive charge of the particle are able to leave the particle. Therefore, the lower estimate of the number of emission electrons even at $T = 2000$ K and a small value of the thermionic electron work function (Φ) does not exceed 2,000 electrons with particle radius of $5 \cdot 10^{-5}$ cm.

Lifetime free electrons does not exceed 0.2 seconds. Concentration emission electrons in air at the surface of particles depending on the temperature and function [25]

$\Phi = E_0 - F$ is expressed as:

$$n_e = 4\sqrt{2} \left(\frac{\pi m k T}{h^2} \right)^{3/2} \exp \left\{ -\frac{\Phi}{kT} \right\} = 4,81 \cdot 10^{15} T^{3/2} \exp \left\{ -\frac{\Phi}{kT} \right\} \text{ elektr./sm}^3, \quad (13)$$

where $h = 6,62 \times 10^{-27}$ erg s – is Planck's constant.

The range of values for F salts : 0,78-5,14 eV; for oxides : 0,71-4,7 eV.

Table 2 illustrates a strong dependence of Ne on T and F. It does not take into account the effect of the positive charge of the particles after the start of the emission of electrons, which electric field prevents the removal of electrons from the surface of the particles emitted electrons returning back to the particle volume.

Table 2. Electron density N_e emission cm^{-3} at the surface of the particles, calculated from formula (13) depending on the temperature T and thermionic work function Φ [26].

F, eV	T, K			
	2000	1500	1000	700
5,14	$4,93 \times 10^7$	$1,56 \times 10^3$	$2,0 \times 10^{-6}$	0
4,0	$3,66 \times 10^{10}$	$2,17 \times 10^7$	1,10	0
3,0	$1,20 \times 10^{13}$	$2,38 \times 10^{10}$	$1,19 \times 10^5$	$2,34 \times 10^{-2}$
1,8	$1,26 \times 10^{16}$	$2,53 \times 10^{14}$	$1,31 \times 10^{11}$	$1,00 \times 10^7$
1,25	$3,06 \times 10^{17}$	$1,78 \times 10^{16}$	$7,72 \times 10^{13}$	$9,08 \times 10^{10}$
0,71	$7,05 \times 10^{18}$	$1,15 \times 10^{18}$	$4,05 \times 10^{16}$	$9,96 \times 10^{14}$

Based on the known theoretical concepts found that all emission electrons go to the formation of negative ions of oxygen molecules. Based on the fact that under the temperature conditions up to 2000 K relatively high density of air is retained, and hence the frequency of

molecular collisions with ions. It is assumed that at such high temperatures all the negative ions capture several neutral molecules and convert into the light ions.

From the start of the thermionic emission the light ions move in directed and diffusion flows and fall as on emitting particles, as on the colder particles without emission. However, getting negative ions on emitting particles reduces their positive charge, which prevented a large output emission electrons. It is therefore considered that negative ions that get on the emission particles on average does not reduce their charges, which is inevitably offset by additional output of electrons. Ions fall only on the emission-free particles, which acquire a negative charge. In connection with that it is important to consider the formation of the ionized channel.

Calculation of the collision of charged aerosol particles with cloud droplets and, consequently, their growth is associated with electric coagulation, conducted by the formula K_t from [19]:

$$N(r_1, q_1; r_2, q_2) = E(r_1, q_1; r_2, q_2) K_t n_1(r_1, q_1) n_2(r_2, q_2) \tau \quad (14)$$

where E - the coefficient of capture ; K_t - the coefficient of turbulence ; r, q - radii and charges of the colliding particles ; τ - time.

Capture coefficient E was taken equal to 5 to 50, according to [12]. The main criteria for selection of E , both for unlike and like-charged droplets were the product of the charges of the colliding drops. Formula (14) applies only to binary collisions of drops. As the collision of droplets leading to their fusion, the number has not yet faced droplets decreases. However, reducing the number of colliding droplets from those already collided was not considered. This was offset by a very small selection of the time step (no more than 0.5 s).

If the drop even after this small time step calculation experienced multiple collisions, this leads to an underestimation of the number of collisions. Taking into account only the initial radius of the drop, which increases depending on the number of collisions. Possible significant number of collisions could change the initial capture coefficient.

At the beginning of the collision of drops the most probable collisions are taken into account: the positively charged droplets with the negatively charged. Number of collisions of negatively charged droplets with every kind of positive droplets depends on the concentration of the latter. To take this into account when allocating negative drops on positively charged droplets weighting factors of such distribution were found. First, there was formally calculated the collision of total concentration of negatively charged droplets with every variety of positive droplets, as if only such a variety of positively charged droplets exist. Then these collisions were summed, and the weighting factors were found as the ratio of the number of collisions with the selected variety of positive droplets to the total number of collisions with all sorts of positive droplets.

Calculated from the weight factor of the true value of the number of collisions N_{coll} at a known concentration of a certain kind of drops there was calculated a ratio of the number of collisions to the concentration of positive droplets. In other words, the amount of negative droplets caught on a positive drop. In the case where the ratio is fractional, the concentration of positively charged droplets is distributed on a whole number of collisions. Thus, for example, more than two but less than three collisions: the concentration of positively charged drops with reduced charge was equal to two negative charges of negative drops, equaled $3n(qe_+) - N_{coll}$ and with three collisions equaled $N_{coll} - 2n(qe_+)$, where $n(qe_+)$ - is the initial concentration of positively charged droplets , and N_{coll} is their collision with negative drops. Similar relations can be easily obtained for any fractional value of the collision.

The collision of droplets was accompanied by their condensation growth and a decrease in their concentration due to turbulent diffusion. Taking into account the ratio between the intensities of these processes, as generally accepted method, for the splitting of the physical processes for each time interval, condensational growth of droplets was primarily assessed,

followed by the assessment of the average decrease in their concentration in the beginning and end of the time interval, and finally – the electric coagulation.

Our task was only to show that artificially charged droplets formed with the participation of charged aerosol particles, even apart from the inevitable interaction their with the natural environment drops, lead to the cloud sizes that match the gravitational coagulation and the creation of the ionized channel.

During the interval 2.5-3 there is a collision of drops with the charge exceeding $272e^+$ and negative drops with the charge exceeding $232e^-$. Considering the diffusion in one liter of cloud environment there will form positive drops with the concentration $2.53 \cdot 10^5 \text{ liter}^{-1}$ and the radius of 14.6 micrometers. Thus, after the introduction of charged reagent into a cloud, a system will form in a cloud environment: artificially created positively charged droplets with a charge of $856 - 3880e$, a concentration of $2.53 \cdot 10^5 \text{ liter}^{-1}$ with drop radius of 14.7 micrometers and negatively charged droplets with a charge over $332e^-$, the concentration of $0.2 \cdot 10^7$ with drop radius 9.1 micrometers, on the one hand ; on the other hand, the system cloud droplets natural origin with radius greater than at least 10 micrometers, the concentration of several thousands per liter cloud environment [12].

Example implementation of the method was held August 18, 2008 over the Gulf of Finland. Over the waters of the bay in the afternoon (15-16 h) was located ridge convective clouds with a lower limit of 600 meters and an upper limit of 3000 m along the ridge on the north side at the side of the cloud with a light aircraft at an altitude of 2900 m with an interval of 7 km 5 products were released pX -26 FHS . As a result, in 4 cases observed lightning discharges from the cloud top to the bottom border of the PC during the burning, weak rain storm and natural lightning discharges were observed.

Promising input devices into the atmosphere can serve as a device for shooting squibs from the aircraft , anti-hail rockets "Ac" , "Alan - 3" , " Alazan -9 " [26] designed to run with anti-hail systems " Elia MR -60 " and " Elia -2- 60", as well as products of firework type Single-launchers and multilateral settings and other products equipped with pyrotechnic composition according to the patent of the Russian Federation [20].

CONCLUSION

Given is the definition of two types of electrical instability in the cloud: micro-electric instability of cloud drops, defined by the Rayleigh limit; and macro-electric instability of space charges in cumulonimbus clouds, which leads to an electrical discharge, named after a Russian scientist – the Imyanitov limit.

The mechanism of separation of electrical charges in the cloud is based on the analysis of experimental data obtained by different authors in the twentieth century. Convective clouds in the stage of development and stabilization consist of upward and downward movements. Positively charged particles rise to the top of the cloud by upward movements on the surface of cloud droplets and by individual ions, as the negative ions are used to form cloud droplets. Negative ions are transported to the top of the cloud inside the cloud droplets under the EDL. With the downward movement, positively charged ions evaporate from the surface of the droplets, forming a positive space charge at the top of the cloud. The remaining part of the negatively charged cloud droplets form a negative space charge. Large drops will fall, but small droplets formed during the fragmentation in accordance with the achievement of the Rayleigh limit, will go to the formation of new large droplets. Chain formation process of space charges and precipitation will continue.

Developed and tested is thermionic method of electric discharge of convective clouds by creating ionized channel in the atmosphere. Used is the pyrotechnic method for generating charged reagent using alkali metals of the Periodic Table of Mendeleev. Application of the charged reagent in a developing cloud increases the conductivity within the cloud and lowers voltage.

Thermionic method of creating an ionized channel is operational and environmentally friendly because the products of combustion of the pyrotechnic mixture are safe for the environment. The method can be used to protect the fuel and energy complex, buildings, aircraft, forestlands and other objects from being struck by lightning, as well as to deal with natural hazards such as tornadoes, hail, heavy rainfall, forest fires and others, accompanied by thunderstorms.

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