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NEW HYPOTHESIS AND ELECTROPHYSICS NATURE OF ADDITIONAL MECHANISMS OF ORIGIN, ACCUMULATION AND DIVISION OF ELECTRIC CHARGES IN THE ATMOSPHERIC CLOUDS OF EARTH

Purpose. Development of new hypothesis about the possible additional mechanisms of origin, accumulation and division of electric charges in atmospheric clouds, containing shallow dispersible drops of water, shallow particulate dielectric matters and crystals of ice. Methodology. Electrophysics bases of technique of high voltage, theoretical bases of the electrical engineering, theoretical electrophysics, theory of the electromagnetic field, technique of the high electric and magnetic fields. Results. Pulled out and grounded new scientific supposition, related to possible existence in earthly troposphere of additional mechanisms of origin, accumulation and division of electric charges in the atmospheric clouds of Earth, being based on electrization in the warm ascending currents of air of shallow round particulate dielectric matters, getting in an air atmosphere from a terrene and from the smoke extras of industrial enterprises. By a calculation a way it is shown that the offered additional electrophysics mechanisms are able to provide achievement in the atmospheric clouds of such values of volume closeness of charges, total electric charge and tension of the electrostatic field stocked in them inwardly and on the external border of storm clouds which correspond modern experimental information from an area atmospheric electricity. The calculation estimations of levels of electric potential and stocked electric energy executed on the basis of the offered hypothesis in storm clouds specify on possibility of receipt in them of ever higher electric potentials and large supplies of electric energy. The obtained results are supplemented by the known approaches of forming and development in earthly troposphere of the electric charged atmospheric clouds, being based on electrization in the warm ascending streams of air the masses of shallow round aquatic drops. Originality. First on the basis of the well-known theses of technique and electrophysics of high voltage the important role of shallow round particulate dielectric matters, electrifiable in the warm ascending currents of air of troposphere is scientifically grounded, in the processes of origin, accumulation and division of electric charges in the stratified-rain, heap rain and storm clouds of Earth. Practical value. Application of in practice findings will allow to deepen scientific and technical knowledge of humanity in area of nature of atmospheric electricity, will be instrumental in further development of physics of linear lightning, decision of global problem of lightning protection of earthly technosphere, and also development of the specified approaches at description of the scantily explored people electrophysics phenomena and theories of thunderstorm at sandy storms in the numerous deserts of the world and powerful smoke eruptions of volcanoes on Earth. References 13, figures 2.

Key words: **atmospheric electricity, new mechanisms of origin, accumulation and division of electric charges in atmospheric clouds, hypothesis, calculation, experimental data.**

Выдвинуто новое научное предположение, связанное с возможностью существования дополнительных механизмов возникновения, накопления и разделения электрических зарядов в слоисто-дождевых, кучево-дождевых и грозовых атмосферных облаках, формируемых в тропосфере планеты Земля. В основу новой гипотезы положены электрофизические процессы в воздушной атмосфере, базирующиеся на присутствии в ней электризуемых в теплых восходящих воздушных потоках мелких твердых диэлектрических частиц сферической формы, имеющих объемную плотность по порядку величины равную объемной плотности в атмосфере мелких водяных капель. Путем расчетных оценок обоснованно показано, что предлагаемые дополнительные механизмы формирования и развития атмосферных облаков способны обеспечивать достижение в них экспериментально подтвержденных уровней объемной плотности облачных зарядов, суммарного запасаемого электрического заряда и напряженности электрического поля. Полученные результаты будут способствовать дальнейшему развитию природы атмосферного электричества, физики линейной молнии и решению глобальной проблемы молниезащиты земной техносферы. Библ. 13, рис. 2.

Ключевые слова: **атмосферное электричество, новые механизмы возникновения, накопления и разделения электрических зарядов в атмосферных облаках, гипотеза, расчет, экспериментальные данные.**

Introduction. Despite the great progress achieved so far in unraveling the secrets of the origin of atmospheric electricity, which are rooted in the fundamental scientific ideas and pioneer works of the 18th century by the outstanding physicists of the world – the Russian M.V. Lomonosov [1] and the American B. Franklin [2] in this field of human knowledge, according to the authoritative electrophysics of our time, electrophysical processes associated with the formation and development of thunderclouds in the Earth atmosphere can not be considered as reliably described and finally studied [3]. It should be noted that under the atmospheric cloud is meant the accumulation of small water droplets (supersaturated water vapor), small ice crystals and small solid particles raised up from the surface of the earth and from the smoke emission zones of operating industrial enterprises (for example, powerful thermal power stations) into the troposphere the lower part of the terrestrial atmosphere up to 11 km high in temperate latitudes, which contains 4/5 of the entire mass of the atmosphere, almost all the water vapor and clouds develop [4]) by warm ascending air currents [3]. As for the concept of an atmospheric lightning cloud, it becomes one of a cumulonimbus cloud in the fulfillment of a number of critical conditions formulated in [3]. It is known that the above processes include [3]: various mechanisms of electrization of liquid and solid particles of clouds; the processes of generation, existence, accumulation and separation of electric charges in a large-scale cloud region with inhomogeneous local temperature and velocity regimes; processes of formation of electric fields in the fine-dispersed medium of clouds; electric discharge phenomena in thunderclouds and the surrounding air atmosphere, which significantly affect the functioning of the electronics of technical means, the human habitat and its vital activity. Without studying these scientific processes that are difficult from the scientific point of view, characteristic for all territories of our planet, further development of physics of lightning, lightning protection and understanding of the role of charged clouds in the global electric circuit of the Earth is impossible.

It should be noted that since the establishment of the electrical nature of linear lightning (a long spark discharge in the air atmosphere [5-8]), about 80 theories have been proposed in the world [3], describing this global natural phenomenon in one or another approximation. Nevertheless, today there is not a single theory of this complex electrophysical phenomenon, which reliably explains many experimental data known to observing specialists. Therefore, further development and improvement of not only these theories, but also individual moments, as well as mechanisms in describing the course of these processes in the atmospheric storm cloud, are urgent scientific problems in the world.

According to [3, 7, 8], the main attention of electrophysicists when considering the initial stage of charge formation in the clouds was turned to the electrification of shallow water droplets in the warm ascending air currents of the atmosphere. For reasons unknown to the author, small solid particles moving in the above air streams were simply forgotten. But they, like water droplets, are capable of electrifying in ascending air currents and further participation in the processes of accumulation and separation of electric charges in atmospheric storm clouds. The natural processes of active electrification of small solid particles in warm airflows are clearly evidenced by the often observed thunderstorms occurring during sandstorms in the deserts of the world and powerful eruptions of volcanoes on the Earth (Fig. 1) [9]. In the author’s opinion, only an integrated and multifaceted approach to the problem of the origin of atmospheric electricity can help to solve it.

The goal of the paper is the development of a new hypothesis on possible additional mechanisms for the formation, accumulation and separation of electric charges in atmospheric clouds containing finely dispersed water droplets, small solid dielectric particles, and ice crystals. Let us emphasize that the term «*hypothesis*» used is derived from the Greek word «*hypothesis*» – «*assumption*» [4] and in the case under consideration is a scientific suggestion made to explain these electrophysical processes in an atmospheric cloud.

Fig. 1. General view of lightning discharges occurring in the volcanic hot smoke zone of an eruption containing fine solids in the ashes [9]

1. Problem definition. Let us consider the large-scale region of the air atmosphere (troposphere) of the Earth in the warm spring-summer period of the year, in which formation of stratus-rain, cumulonimbus and storm clouds is possible. To this end, we believe that in this area there are: firstly, water vapor and small drops of water; second, small solid dielectric particles (for example, silica – quartz); third, the ascending warm and descending cold air currents; fourth, small ice crystals in the form of snowflakes and granules. Possible mechanisms of electrification in the considered region of the earth's atmosphere of small drops of water are considered in detail in [3, 7]. In this paper, the main emphasis will be placed on the possible role of these solid particles in the formation, accumulation and separation of electrical charges of both polarities, initially in a cumulonimbus cloud, and then in a thunderstorm cloud. To this end, we assume that the small solid particles moving in the warm ascending air stream have the form of a sphere of radius r_0. We assume that the average concentration (density) of these solid particles in the atmospheric air is N_0. Calculated estimates of the electrization processes of the solid dielectric particles under consideration and the accumulation of a volume electric charge with them in the atmospheric cumulonimbus cloud can be performed for the case of normal atmospheric conditions (air pressure is $1,013\cdot10^5$ Pa, and its absolute temperature T_0 is 273.15 K [10]). These conditions are close to the lower boundary of the level of the isotherm, in the zone of which cloud charges begin to be created [3]. It is required, in the approximation considered, to consider possible additional mechanisms for the formation, accumulation and separation of electric charges in the cumulonimbus and then in a thunderstorm cloud, due to the presence of these solid dielectric particles moving in the warm upward airflow.

2. Calculation estimation of the process of electrification of solid particles in an ascending warm air stream. The results of the studies presented in [3, 7] indicate that the processes of electrification in the air atmosphere of our planet have a bipolar nature. In addition, according to the data of [3], the ionic mechanism of electrization of cloudy particles is characteristic for the initial stage of cloud development in the terrestrial atmosphere. The contact mechanism of particle electrification is the main mechanism leading to the appearance of unipolarly charged regions in atmospheric clouds. The mechanism of electrification of particles in an external electric field can substantially manifest itself in atmospheric cumulonimbus and storm clouds. Proceeding from the results of the influence of these mechanisms of electrization of cloud particles, described in detail in [3, 7], on the finely dispersed dielectric inclusions of a spherical shape moving in the ascending heat, we limit ourselves to the case where the received solid particle of radius r_0 received a free electric charge q_0 of negative polarity, uniformly distributed over its outer spherical surface. We assume that the negatively charged particle of radius r_0, when moving in an ascending warm air flow, is capable of pulling polarized water molecules radially oriented along this field due to the action of its own radial electric field to its outer spherical surface (Fig. 2). As a result, a solid spherical particle with a charge q0 will be surrounded from the outside by a cluster (micro-cloud) of water vapor and, accordingly, covered with a thin water film. Such a state of the investigated charged solid particle of radius r0 will not contradict any of the known physical positions.

And, as in a charged water spherical droplet [3], the outer part of the «particle – water film» system will also have a negative electric charge, but not free, but bound (see Fig. 2). At the molecular level, the electric charges of each water dipole of this system are bound and held intramolecular Coulomb forces [10]. Therefore, there is no neutralization of the free charge q_0 of a solid dielectric particle of radius r_0 due to the presence of electrically neutral molecules near the water. In accordance with the fundamental principles of electrophysics, a double electric layer (DEL) of thickness Δ_e (see Fig. 2) between the electrons of a solid particle of radius r_0 and the first layer of molecular dipoles of water will form on the inner boundary of the «particle – water film» system. The associated positive charge q_+ of each such molecular dipole of water in the DEL zone will be $10e_0$, where $e_0=1.602\cdot10^{-19}$ C is the module of the electric charge of the electron [10]. It is known that the thickness Δ_e of the DEL in the resulting «particle – water film» system will be determined in the form [10]:

$$\Delta_e=\left[\varepsilon_0 kT_0/(n_0 q_+^2)\right]^{1/2}=\left[10^{-2}\varepsilon_0 kT_0/(n_0 e_0^2)\right]^{1/2}, \quad (1)$$

where $\varepsilon_0 = 8.854\cdot10^{-12}$ F/m is the electrical constant; $k = 1.38\cdot10^{-23}$ J/K is the Boltzmann constant; n_0 is the concentration (density) of molecular dipoles of water.

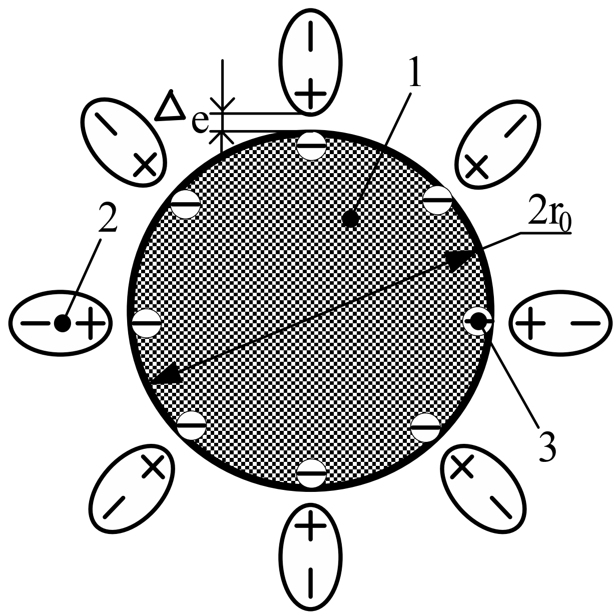

Fig. 2. Simplified view of a negatively charged solid spherical particle surrounded by electrically neutral polarized water molecules (1 is a solid particle, 2 is a molecular dipole of water, and 3 is an electron)

In the case when the molecular dipoles of water suspended in the atmospheric vacuum satisfy the state of an ideal gas, their density n_0 under the normal atmospheric conditions used in the first approximation can be taken equal to the Loschmidt number numerically equal to $N_L=2.68\cdot10^{25}$ m^{-3} [10] . Then it follows from (1) at $T_0=273.15$ K, $n_0\approx2.68\cdot10^{25}$ m^{-3} and the above-mentioned world constants (ε_0, k and e_0) that $\Delta_e\approx0.22\cdot10^{-10}$ m that even a rough numerical estimation of the thickness Δ_e of the DEL in the system «particle – water film» does not go beyond the reasonable values commensurate with the radius of the atom of a solid dielectric particle [10]. In addition, we note that the Debye shielding radius (length) Δ_D is the same as for a low-temperature plasma containing electrons, ions and neutral atoms (molecules), and a solid-state «metal plasma» (an electrically neutral substance consisting of a negatively charged «electron gas» and ionized positively charged metal atoms) corresponds in order of magnitude to the value of Δ_e found [10, 11]. In order to be more convincing in the correctness of the estimated estimate Δ_e by (1), we indicate that the Debye radius Δ_D characterizes the distance (linear dimension) at which the Coulomb field of any charge of the plasma is screened by a charge of the opposite sign. It is precisely this situation that is observed in the indicated DEL of the «particle – water film» system under investigation (see Fig. 2).

Now, using the «particle – water film» electrostatic system formed in an ascending warm air stream with its DEL, it is possible to return to the estimated evaluation of the negative electric charge q_0 that appears on the outer spherical surface of a moving solid dielectric particle of radius r_0 due to its electrification in the air atmosphere. Applying the provisions of the well-known theory of DES [3, 10], for the electric charge q_0 of a solid particle in the «particle – water film» system, we find:

$$q_0 = 4\pi\varepsilon_0 r_0 \varphi_0 , \qquad (2)$$

where φ_0 is the Helmholtz electrokinetic potential of (in the case of pure water in the electrostatic system being considered, $\varphi_0 = 0.25$ V [3]).

It can be seen from (2) that for the calculated estimation of the charge q_0 on the outer surface of the earth's atmosphere of the solid dielectric particle, which is electrified in the ascending heat, it is necessary to specify the numerical value of its radius r_0. According to [3], in the layered rain and cumulonimbus clouds, solid particles with a radius r_0 of (5-10) μm can be present. At $r_0 \approx 10 \cdot 10^{-6}$ m and $\varphi_0 = 0.25$ V, we obtain from (2) that the charge of electrification of a solid dielectric particle in an ascending warm air atmospheric flow is numerically equal to approximately $q_0 \approx 2.78 \cdot 10^{-16}$ C. Such a value of the negative electric charge q_0 of solid dielectric particles of radius $r_0 \approx 10$ μm is in good agreement with the data given in [3] and typical for the contact mechanism of the charge of drops of pure water in the ascending warm air stream of the Earth atmosphere. Assuming that in the first approximation the volume density N_0 of solid dielectric particles in the atmospheric cloud is of the order of magnitude of the concentration of water droplets in it and is numerically about 10^8 m^{-3} [3], for the volume density σ_V of the electric charge in a thundercloud due to the presence in it electrified solid dielectric particles of radius r_0, we use the following calculation relation:

$$\sigma_V = q_0 N_0 . \qquad (3)$$

From (3) for $q_0 \approx 2.78 \cdot 10^{-16}$ C and $N_0 \approx 10^8$ m^{-3} it follows that in the case under consideration $\sigma_V \approx 2.78 \cdot 10^{-8}$ C/m^3. This numerical value σ_V obtained with allowance for (2) and (3) corresponds to the experimental data for the mean value of the space charge density in a thunderstorm cloud [3, 7]. For example, with an average overall size of a thunderstorm cloud of 1 km × 1 km × 4 km (horizontal dimensions and size in height) and its corresponding volume $V_0 \approx 4 \cdot 10^9$ m^3, the specified value $\sigma_V \approx 2.78 \cdot 10^{-8}$ C/m^3 causes appearance in the given cloud of the total electric charge $q_\Sigma \approx \sigma_V V_0$, by modulus equals about 111 C. This charge indicator q_Σ correlates well with known probabilistic experimental data characterizing the electric power of such a cloud [3, 5-7].

From (2), for the surface density σ_S of a charge on a solid dielectric particle of radius $r_0$which is electrified in the air atmosphere, we have:

$$\sigma_S = q_0 / (4\pi r_0^2) = \varepsilon_0 r_0^{-1} \varphi_0 . \qquad (4)$$

At $r_0 \approx 10 \cdot 10^{-6}$ m и $\varphi_0 = 0.25$ V, we find from (4) that the value of σ_S for a solid spherical dielectric particle under study assumes a numerical value equal to approximately $2.21 \cdot 10^{-7}$ C/m^2. Note that this calculated value of σ_S is almost two orders of magnitude higher than the average surface density of the negative charge of the planet Earth, which is about 10^{-9} C/m^2 [3]. Taking into account (4) and [10], for the intensity E_0 of the electrostatic field near the surface of a solid dielectric particle of radius r_0 that is electrified in the warm ascending air stream of the Earth, we find:

$$E_0 = \sigma_S / \varepsilon_0 = \varphi_0 / r_0 . \qquad (5)$$

From (5), at $\varphi_0 = 0.25$ V for a solid dielectric particle of radius $r_0 \approx 10 \cdot 10^{-6}$ m which has undergone atmospheric electrification, we find that near its negatively charged spherical surface, the electrostatic field strength E_0 can be numerically equal to approximately 25 kV/m. It is likely that such an electric field is capable of pulling the dipoles of polarized water molecules to the surface of the particle under study. With regard to the mean electric field strength in layered rain and cumulonimbus clouds, according to direct experimental measurements by flying directly in the clouds of the electrophysical laboratory, it can reach the level (20-30) kV/m in the pre-threat period (before the transition of these clouds into thunderstorms) [3, 7]. These data may indicate the validity of the estimated estimate from (5) of the value of E_0 near the particle to the formation of a «particle – water film» system.

The probable numerical values of the intensity E_e of the electrostatic field in the DEL zone of the «particle – water film» system can be approximately determined from the following calculated expression:

$$E_e = \varphi_0 / \Delta_e . \qquad (6)$$

Then from (6) at $\varphi_0 = 0.25$ V and $\Delta_e \approx 0.22 \cdot 10^{-10}$ m, which follows from the approximate calculation by (1) with the accepted initial data ($T_0 = 273.15$ K; $n_0 \approx 2.68 \cdot 10^{25}$ m^{-3} [10]), it follows that in the zone of the DEL under consideration the intensity E_e of the electrostatic field will reach a huge numerical value of about $1.13 \cdot 10^{10}$ V/m. This level of E_e indicates that an extremely high electric field arises in the zone of the DEL of the «particle – water film» system under investigation, which determines the electric energy W_e accumulating by the atmospheric thunder cloud.

3. Phenomenological description of the processes of accumulation and separation of electric charges in an atmospheric cloud with solid particles. Raised in the terrestrial troposphere by an ascending warm air flow, charged solid dielectric particles of radius r_0 shielded from the outside by a protective thin water film and simultaneously forming a DEL with its superhigh electrostatic field will contribute to the volumetric accumulation of electric charges in the stratified rain and cumulonimbus clouds under consideration with their volumetric density σ_V. In the author's opinion, in the absence of the protective electrically neutral microspectra surrounding them from the molecular dipoles of water in the absence of charged particles with the same name, physical difficulties in their directed concentrated collection in the troposphere are possible. One of their manifestations may be premature intra-cloud electric discharges (as in volcanic smoke eruptions), leading to partial neutralization of electrification charges for small solid particles. This circumstance will also be facilitated by the fact that, taking into account the previously noted bipolar character of the electrization of solid dielectric particles in the air atmosphere [3], large-scale regions with excessive negative (with an excess of electrons) and positive (with a lack of electrons) by electric charges. On the one hand, it is known from the theory and practice of atmospheric electricity that the upper part of these clouds is in the zone of action of low isotherms (up to –40 °C) [3, 7]. Naturally, in this part of the clouds under consideration, there will be processes of water crystallization (including a thin water film covering a charged solid dielectric particle). And if this is so, then this freezing water film will collapse (due to its volumetric expansion during the crystallization process) (almost explode, like the freezing drop of water [3]) and leave the outer surface of a solid dielectric particle that previously had an excessive negative electric charge q_0. On the other hand, it is also known from the theory and practice of atmospheric electricity that ice crystals formed of electrically neutral pure water with its molecular polarized dipoles (including a thin water film covering the investigated charged solid dielectric particle) have a negative electrical potential and, accordingly, excess negative charge (excess of electrons) with respect to water (Workman-Reynolds effect) [3, 10]. On the appearance of this electrical potential, when a liquid and solid phase of a substance is transformed in the freezing water, the upper layers of the troposphere perform certain work. Proceeding from the fundamental law of nature on the conservation of electric charge [10], it can reasonably be assumed that in the described process of separation of electric charges in the upper supercooled part of the atmospheric cloud, the example of one electrostatic system «particle – water film» is the spherical surface of a solid dielectric particle released from the water film remains negatively charged with charge q_0. All this together (the disappearance of the negative charge q0 from the charged solid particle and the presence of the negative charge q_0 on this particle, and the presence of negatively charged snowflakes and granules due to the crystallization of water vapor in the supercooled part of the cloud) will contribute to an increase in the electric field strength in considered part of the atmospheric cloud.

From applied electrophysics, connected with the study of atmospheric electricity, it is known that at the stage of transition of the cumulonimbus cloud to the thundercloud in its middle and lower parts processes must actively occur, accompanied by the movement of warm ascending and cold descending air masses, as well as the presence of precipitation of rainfall [3]. It is under these conditions that there is a significant increase in the intensity of the electric field inside the thunderstorm cloud, reaching a level of about 0.4 MV/m and more [3], at which it is possible to develop electric discharge processes both inside and outside the cloud, including of the earth's surface. Considered within the framework of the proposed hypothesis on the nature of additional mechanisms for the development of electrophysical processes in atmospheric clouds, the electrostatic system «particle – water film» can justify physically the significant increase in the electric field strength inside and outside the thunderstorm cloud in the case of active release of accumulated moisture vapor in it precipitation from it rainfall. It is in this case that there is a violation of the screening of charged solid dielectric particles by the dipole layers of water vapor (a kind of screening of the electric field of these particles), which carry an excess charge of the cloud q_Σ and provide, with the average volumetric density σ_V, over the atmospheric cloud, in their totality, the formation of the electrostatic field of a thunderstorm cloud.

4. Calculation estimation of the electric field strength inside and outside the thunderstorm cloud with solid particles. For this ion let us use a simplified computational model of a thunderstorm cloud having the form of a sphere of radius R_0 inside which are uniformly distributed with volume density $\sigma_V\approx 2.78\cdot 10^{-8}$ C/m^3 electric charges $q_0\approx 2.78\cdot 10^{-16}$ C of individual little solid dielectric particles with radius $r_0\approx 10\cdot 10^{-6}$ m. We assume that the total electric charge of these particles $q_\Sigma\approx 111$ C, as in section 2, is concentrated in a thunderstorm cloud with the volume $V_0=4\pi R_0^3/3=4\cdot 10^9$ m^3 and corresponding to a radius of approximately $R_0\approx 985$ m. Proceeding from the application of the Ostrogradsky-Gauss theorem [10], for the intensity E_r of the electrostatic field inside the assumed computational model of a thunderstorm cloud of spherical shape at the current value of the radius $r<R_0$, we find:

$$E_r = q_\Sigma r/(4\pi\varepsilon_0 R_0^3) \,. \quad (7)$$

From (7) at $R_0\approx985$ m, $r\approx R_0/2\approx492.5$ m and $q_\Sigma\approx111$ C, we obtain that in the investigated case $E_r\approx0.514$ MV/m. It can be seen that within a thunderstorm cloud containing solid precipitates of electrically neutral water vapor (films) previously electrified in a warm ascending air stream, solid dielectric particles of radius $r_0\approx10$ μm with their volume density $N_0\approx10^8$ m^{-3} in the Earth atmosphere, it is possible to reach critical values of the strength E_r of the electrostatic field, which are characteristic in accordance with [3, 7] for electric discharge processes in the investigated clouds.

For the strength E_R of the electrostatic field at the outer boundary ($r=R_0$) of the calculated storm cloud model from the theory of electrostatics, we have:

$$E_R = q_\Sigma/(4\pi\varepsilon_0 R_0^2) \,. \quad (8)$$

Substituting in (8) the accepted initial data ($q_\Sigma\approx111$ C; $R_0\approx985$ m), for the required electric field strength E_R on the outer boundary (edge) of the considered thunderstorm cloud model, we obtain a numerical value equal to approximately 1.03 MV/m. The quantitative calculation data for E_R obtained with the help of (8) and proposed additional mechanisms for the formation and flow of electrophysical processes in atmospheric clouds, indicate the possibility of development from the outer boundary of the described model of a thundercloud of avalanche clouds [3] which are a precursor of a spark breakdown in an atmosphere of a long air gap (lightning).

5. Calculation estimation of the electric potential of a thunderstorm cloud with solid particles. It is known from electrostatics that the electric potential φ_R outside the considered simplified computational model of a thunderstorm cloud of spherical shape (for $r\geq R_0$) with the total electric charge q_Σ containing uniformly distributed over its volume q_0 small fine particles, can be calculated by the following approximate formula [12]:

$$\varphi_R = q_\Sigma/(4\pi\varepsilon_0 r) \,. \quad (9)$$

From (9) at $r \approx R_0 \approx 985$ m and $q_\Sigma \approx 111$ C we find that on the outer edge of the lightning cloud under study, $\varphi_R\approx1.01\cdot10^9$ V. It is possible that due to the geometric shape of the calculated region of the thunderstorm cloud and the quantitative of the volumetric density N_0 in it of solid dielectric particles of the order of 10^8 m^{-3}, the numerical values of the electric potential φ_R according to (9) are too high. Thus, according to [13], the difference in electrical potentials between a thundercloud and earth can reach a level of about 100 MV. Assuming in the estimated calculations for (3) the volumetric density σ_V of the electric charge for the lightning cloud under consideration $V_0\approx4\cdot10^9$ m^3 ($R_0\approx985$ m) and its total electric charge q_Σ, $N_0\approx10^7$ m^{-3} (an order of magnitude less than the possible volumetric density in an atmospheric cloud of shallow water droplets), it is easy to come according to (9) to the calculated level of the electric potential of a thunderstorm cloud, $\varphi_R\approx101$ MV, practically indicated in [13]. This value of φ_R appears to the author more plausible for the storm cloud under study. Such a corrected value of N_0will cause, respectively, a tenfold drop in the previously given electrophysical characteristics for the cloud as σ_V, q_Σ, E_r and E_R. In this case, the proposed electrophysical mechanisms for the formation and development of a thundercloud in the terrestrial troposphere are in fact additional to the known mechanisms for the accumulation of electric charges in it, based on the atmospheric electrization of shallow water droplets in warm ascending air currents. Nevertheless, the estimated calculation values of φ_R obtained above indicate that small ($r_0\approx10$ μm) solid dielectric particles electrified in the warm ascending air flow with a volume density of the order of $N_0\approx(10^7-10^8)$ m^{-3} and a charge of $q_0\approx2.78\cdot10^{-16}$ C, due to the impressive volume of a thunderstorm cloud (of the order of $4\cdot10^9$ m^3) are due to the processes of heat exchange in the atmosphere, the fulfillment of the laws of thermodynamics, which lead to the appearance in the terrestrial troposphere of large zones of various pressures and the movement of huge air mass, forms a quite extended atmospheric electrically charged cloud region carrying ultra high electrical potential and causing the development of lightning.

6. Calculation estimation of the electrical energy stored by a thunderstorm cloud with solid particles. We carry out this estimate proceeding from the assumption that the electric energy W_e of the atmospheric cumulonimbus cloud, before its transition to the stage of a thunderstorm cloud, is stored only in a large number of the electrostatic systems «particle – water film» that we are studying. In this connection, an approximate calculation of the value of W_e for a given volumetric density N_0 of the electrostatic systems under consideration in a pre-threat cloud with a total volume V_0 will be reduced to the determination of the electric energy W_{e0} concentrated in their one DEL with thickness Δ_e. For W_{e0}, we can write the following approximate calculation expression:

$$W_{e0} = 2\pi\varepsilon_0\varphi_0^2 r_0^2/\Delta_e \,. \quad (10)$$

Then from (10) at $\varphi_0=0.25$ V, $r_0\approx10\cdot10^{-6}$ m and $\Delta_e\approx0.22\cdot10^{-10}$ m we find that in one electrostatic system of spherical form a «particle – water film» (in its DEL with superhigh electric field) the electrical energy of about $W_{e0}\approx1.58\cdot10^{-11}$ J is stored. Taking into account (10), for the volume density W_{eV} of electrical energy in a pre-threat cloud with small solid dielectric particles of radius r_0

electrified in the warm ascending air flow of the atmosphere, we have:

$$W_{eV} = W_{e0} N_0 . \quad (11)$$

From (11) at W_{e0}≈1.58·10^{-11} J and N_0≈10^{7}m^{-3} it follows that in a thunderstorm cloud with small (radius r_0≈10 μm) solid charged by atmospheric electrification with dielectric particles, volume density W_{eV} of electric energy, numerically equal to about 1.58·10^{-4} J/m^3. As a result, for the electric energy W_e stored in the storm cloud under study with a total volume V_0, we can write the following calculation relation:

$$W_e = W_{eV} V_0 . \quad (12)$$

At W_{eV} ≈ 1.58·10^{-4} J/m^3 and V_0≈4·10^9 m^3 from (12) we find that in a thundercloud of a given size, during the formation of which, new additional mechanisms for the formation, accumulation and separation of electric charges in atmospheric clouds, the electrical energy W_e can accumulate, which in numerical terms reaches the value of 0.632 MJ. This value of W_e is relatively small. Here it should be emphasized that in the calculation estimation of W_e, we did not take into account the electric charges with their energy, formed in a thundercloud cloud with the known processes of electrization of shallow water droplets and crystallization of cloudy water vapor [3]. At the initially accepted volumetric density in a cloud of small solid particles N_0≈10^8 m^{-3}, the stored electric energy W_e in this spherical model of a thunderstorm cloud (V_0≈4·10^9 m^3), taking into account the proposed hypothesis, will be numerically about 6.32 MJ.

Conclusions.

1. A new hypothesis is presented with the scientific justification for the possible existence of additional mechanisms for the formation, accumulation and separation of electric charges in the atmospheric clouds of our planet based on the electrization in warm ascending air currents of small round solid dielectric particles of radius r_0 falling into the air atmosphere from the Earth surface and from the smoke emissions of industrial enterprises in most countries of the world.
2. It has been shown by calculation that the proposed additional mechanisms for the formation, accumulation and separation of electric charges in atmospheric stratified rain, cumulonimbus and storm clouds are capable of achieving in these types of clouds the values of the volumetric density of σ_V of charges, the total electric charge stored in them q_Σ and the E_r and E_R strengths of the electrostatic field inside and on the outer boundary of similar clouds that correspond to the current experimental data from the atmospheric electricity.
3. Carried out taking into account the proposed hypothesis calculation estimations of the electric potential φ_R in the spherical model of an atmospheric thundercloud with outer radius R_0≈985 m and stored in it electrical energy W_e indicate that the atmospheric electrization of small fine solid particles with radius r_0≈10 μm with their volumetric density N_0≈10^7 m^{-3} in such a cloud is capable of providing an extremely high value of the electric potential φ_R (up to 1.01·10^8 V) on it and the accumulation in it of a very high electric energy W_e (up to 0.632·10^6 J). At N_0≈10^8 m^{-3}, the values considered are, respectively, 1.01·10^9 V and 6.32·10^6 J.
4. The considered electrophysical processes and new additional mechanisms of the formation and accumulation of electric charges in atmospheric clouds can be useful in constructing a thunderstorm theory in natural fine-dispersed media with fine solid particles charged by contact electrization, characteristic of sandstorms and volcanic smoke eruptions, when in them the volumetric density N_0 of small solid dielectric particles is not less than 10^8 m^{-3}.
5. The proposed new additional electrophysical mechanisms for the formation of electric charges in the Earth atmospheric clouds, together with known similar mechanisms based on complex electrization in the warm ascending air stream of shallow round water droplets, will contribute to the further development of the nature of atmospheric electricity and the successful solution of the global lightning protection problem on our planet of technical and biological objects.

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