On the role of vertical temperature gradient in the inductive charge separation mechanism

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***Abstract*— Different types of models exist for cloud electrification in cloud micro-physics, *e.g.*, drop break-up, ion charging, convective mechanism, inductive charging, different types of particle charging involving ice phase and ice crystal/graupel charging etc. Inductive charging is the most convincing process of all. In the inductive charging process the pre-existing electric field induces charges and electrically polarizes the suspended water droplets and ice crystals. Charge transfer occurs as the smaller cloud particle rebounds from the underside of a larger ice particle and thus kinetic energy of droplets is converted to electrostatic potential energy. The larger charged particles come down due to gravity and the reduced gravitational potential is converted to electrostatic potential. Thus, randomly stratified charged region forms in thunder cloud with positive or negative charge centre. Recombination of charges of two opposite charge centers takes place in the form of lightning through the ionization channel and releases huge energy as acoustic and electromagnetic waves spanning various wavelengths. In this article we discuss the inductive charge transfer process as a function of vertical temperature gradient, aerosol content, existing electric field and water vapor content.**

***Index Terms*— Inductive charging, recombination of charges, temperature gradient, thunderstorms**

I. Introduction

Worldwide thunderstorm activity is responsible for maintaining a potential difference of ~250 kV between the ground and the ionosphere at around 50 km altitude where the Earth's surface consists of negative charge and the corresponding positive charge is left in the atmosphere. In general, the cloud electrification process brings the negative charge to ground from the thunder cloud regions in the lower side through precipitation of negatively charged rain drops or negative cloud to ground lightning etc., whereas drives the positive charge up to the ionospheric altitude owing to updraft above the cloud top. The resulting global fair weather electric field is around $-120\ Vm^{-1}$ at the ground and decreases to zero in the conducting region of the ionosphere. C. T. R. Wilson assumed a vertical charge dipole within thunderstorms and determined that the charge regions are usually positive above negative [1]. He measured electric field changes at the ground caused by intra-cloud lightning in which the dipole charges neutralized each other. This proposition was confirmed with extensive electric field change measurements carried out by P. R. Krehbiel and his group in New Mexico in which the locations and values of charges in thunderstorm charge centers were determined [2]. More complicated charge centre distributions have been reported, for example, by M. Stolzenburg and co-workers [3].

There are different types of model for the cloud electrification in cloud micro physics, i.e., drop break-up [4], ion charging [5], the convective mechanism [6], inductive charging [7], different types of particle charging involving the ice phase and the ice crystal / graupel charging etc. The inductive charging is the most convincing process.

According to the inductive charging process the pre-existing electric field induces charges and electrically polarizes the suspended water droplets and ice crystals. Charge transfer occurs by the smaller cloud particle rebounds from the underside of a larger ice particle. During this process the kinetic energy of the droplets is converted to electrostatic potential energy, larger charged particles come down under the gravitational force and then the gravitational potential gets converted to the electrostatic potential. In this article we discuss in detail and try to modify this model in terms of role of temperature gradient and water vapor content.

II. Inductive charge transfer mechanism

The pre-existing vertical electric field induces charges in cloud particle so that small particle rebounds can separate the induced charge from the other and strengthen the field. Initially, the field may be due to the downward directed fair weather field (−E) resulting from positive charges in the atmosphere with a negative ground surface below. The interacting cloud particles have sufficiently high electrical conductivity so that there is time for the induced charges to form in the particles in response to the external electric field. In other planetary atmospheres with materials other than water ice, the particle conductivity along with electrical relaxation time needs to be considered both for the response to a changing external field and the time required for charge transfer. Collisions of water droplets often lead to coalescence and thus the most likely situation in which the inductive process may act in clouds is for rebounding ice/ice or, possibly, ice/water collisions. A smaller cloud particle rebounds from the underside of a larger ice particle in the existing vertical electric field; it removes charge and is carried around the larger particle in the upward moving air-stream. Gravitational separation then occurs with the larger particle

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falling while the oppositely charged smaller particle is carried aloft thereby strengthening the electric field. However, the process does not always work in this manner; Al-Saed and Saunders showed that when pairs of larger drops collided they partially coalesced, swung around each other and separated the induced charge in a way that reduced the ambient field [8]. Experimental studies with ice/ice collisions by Illingworth and Caranti showed that the charge transfer was limited by the purity of naturally occurring ice [9]. Ice has an electrical conductivity high enough to allow the induced charges to form, but low enough that during the brief collision, there is insufficient time for a complete transfer of charge. They found that when the ice was doped to increase its electrical conductivity, the theoretical value of induced charge transfer appropriate to two conducting particles was achieved. For this reason the inductive process involving ice/ice collisions has not been considered a viable mechanism for thunderstorm electrification.

B. J. Mason presented a convincing case from the thunderstorm observations and numerical modeling of the inductive process that it may be a viable mechanism for the case of water droplets rebounding from the underside of ice pellets [10]. Brooks and Saunders carried out studies of this process in a laboratory cloud chamber in which an ice-coated sphere fell through a cloud of super-cooled water droplets in a vertical electric field [7]. They showed that measurable and significant charge transfer was achieved when the droplets rebounded off riming graupel pellets, thus reviving the inductive mechanism. This process may help account for observations in thunderstorms of regions of cloud particles that have acquired their charges very rapidly in later stages of storm development when substantial electric fields are already present.

However, the inductive charging process alone could not justify the observations in the early electrification period of thunderstorms made by Christian and co-workers who showed the charges on graupel (hail pellets of small size) of larger size could have been generated in the maximum electric field strength measured in thunderstorms [11]. These results were obtained from an airborne instrument in a New Mexico thunderstorm in which a cloud particle imager and charge induction device gave corresponding values of charge and graupel size for individual precipitation particles. They concluded that cloud particle charges producing the first lightning stroke are unlikely to be due to the inductive process. Other processes must be responsible for the production of the observed charges in the time available.

According to our model, when a smaller water droplet collides with a larger drop first it merges with the larger one and the induced charge shuffles with it as shown in Fig. 1.

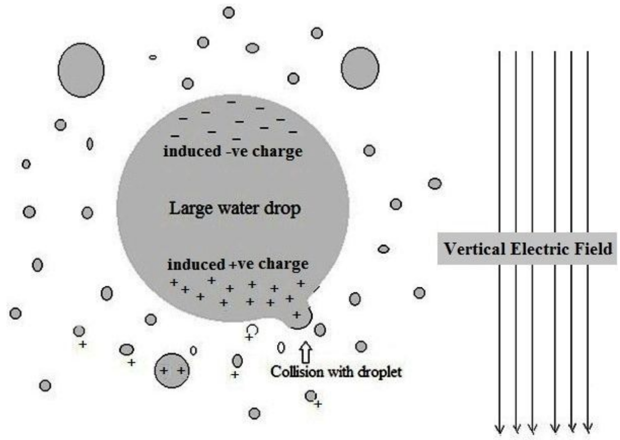

Fig. 1: Charge mixing with the precipitating droplet during collision

Then it breaks-up mostly from the lower part or at the position of collision and comparatively smaller mass comes out with reduced velocity and positive charge during the occurrence of collisions (Fig. 2).

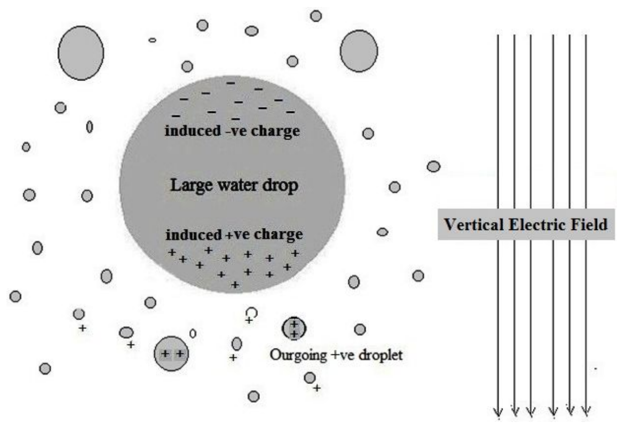

Fig. 2: The positive charge transfer during the collision in the presence of electric field

The velocity of the fragment particle gradually decreases due to net electrostatic force applied by the collided particle.

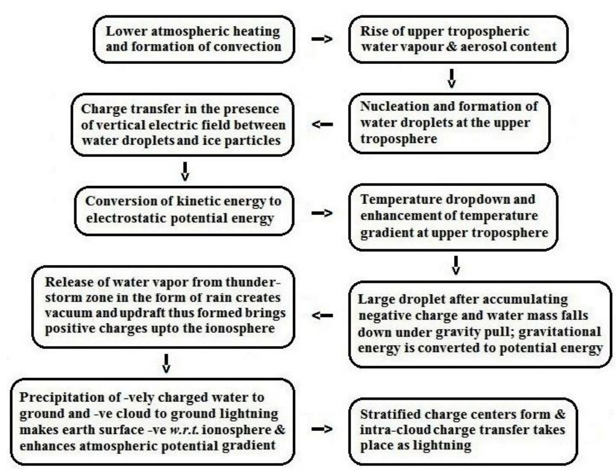

Fig. 3: Outcomes of temperature gradient in the inductive charge transfer process

III. Our propositions

- Induced charge formation in the large droplet due to existing vertical electric field
- Charge transfer occurs during the collision by the exchange of charged mass by the recoiled droplet which is also shrinking back.
- Influence of temperature gradient, *i.e.*, more positive charge transfer from the bottom side than the negative charge transfer from the upper portion.

IV. The role of temperature gradient in the inductive charge transfer process

- Due to the existing temperature gradient, the energy of the lower particles is slightly greater than those in the upper side.
- Charge transfer by the particle colliding at the lower side will be more than the colliding particle at the upper side.
- Net charge transfer makes the large water particle negatively charged.
- Decrement of temperature gradually spreads to lower side due to conversion of energy to electrostatic energy. The lower atmospheric temperature drops down.

At this particular situation the obvious outcomes (Fig. 3) are:

- Net negative charge accumulation in the larger drop.
- The positive charges are released in the surrounding particles by virtue of which atmospheric molecules become positive ions.
- Reduction of kinetic energy of the particles which converted to the electrostatic potential energy.
- Growth of mass of the larger droplet thereafter falling down under gravitational influence.
- The work done by the gravitational pull on negatively charged particles against vertical electric field due to the downward displacement are restored in the form of electrostatic potential energy.
- Decrement of temperature with the reduction of kinetic energy of the surrounding particles.
- The updraft carries the positive charges up to the ionospheric heights.
- As the cumulative effect of these phenomena stratified charge centers are formed at different regions of the thunderstorms and onset of the development of ionospheric potential.

The kinetic energy of the particle which is moving from downward side is slightly larger than that of the particles coming from upward side. Thus the ability of charge transfer of the upward moving particle is more than the downward moving particle. As the lower side is mainly induced with positive charge the collision at the bottom of the large particle transfers positive charge to the outgoing particle from the large particle, whereas the collision at the upper side transfers negative charge to the outgoing particle from the large particle as because the upward side is induced with negatively charge. The probability of positive charge transfer is greater than the negative from the larger drop. The outcome of the net charge transfer shows the large droplet becomes negatively charge. At the same time the large droplet accumulates water mass as some tiny water droplets merge with it during the process of collision.

V. Role of water vapor in the cloud electrification process

- It supplies latent heat to increase the kinetic energy of the particles,
- Enhances the number density of the droplets,
- Enhances the size of the larger water drop duly attaching with it so that the gravitational pull becomes sufficient to pull down the suspended water drop overcoming the upward electrostatic attraction. At that time the work done by gravitational force against electrostatic force is converted to electrostatic potential energy.
- Certain changes from vapor state to liquid state manifest the formation of vacuum. Further release of water vapor in the form of rain or hail mass density at that cloud position certainly dropdown. The cumulative effects of these two phenomena are obvious to form updraft which carries this positively charged zone to the upward direction up to the ionospheric height. As a result the ionospheric altitude becomes positively charged up to almost 250 kV with respect to the ground surface. Thus, the atmospheric vertical electric potential gradient gradually increases due to the thunderstorms.
- Enhances electrification in the presence of some other Aitkin particles due its collisions with the other large drops.

VI. Conclusion

Thus there forms stratified charged region in the thunder cloud with positive or negative charge centre. Further there occurs pulse shaped charge separation in between the two oppositely charged centers induced by the electric field which produces ionization channel through which the recombination of two opposite charge centers takes place thereby releasing huge energy in the form of acoustics and electromagnetic waves comprising of various wavelengths. The authors are in the process of fine tuning the modified version of the theory for the inductive charge transfer process and will communicate the outcome in a separate article.

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