EPH - International Journal of Applied Science
ISSN (Online): 2208-2182
Volume 05 Issue 02 June- 2019

DOI: https://doi.org/10.53555/eijas.v5i2.117

NEW INSIGHT INTO THE LIGHTNING FORMATION

Junsheng Zhang[1*], Qingtian Meng[2]
[*1]*School of Physics and Electronics, Shandong Normal University, Jinan, Shandong, 250358, P. R. China*
[2] *Division of Hospital Equipment, Minmetals Luzhong Mining Co., LTD, Jinan, Shandong 271113, P. R. China*

[*]***Corresponding author**:-*
***E-mail:-**qtmeng@sdnu.edu.cn*

Abstract:-
Lightning is a sudden electrostatic discharge occurring between the charged regions of a cloud, between two clouds, or between a cloud and the ground. Here, based on the law of electro-magnetic induction, we choose the kinds of lightning originated from rotating cloud and volcanic ash as the subjects, by analyzing the processes of charge causing, separating and accumulating in them under the influence of geomagnetic field, to expound the fundamental mechanics of lightning formation. An experiment is designed to verify the rationality of this mechanism indirectly. The related investigation is helpful to interpret correctly the lightning phenomena in nature.

Key words:- *Lightning, Geomagnetic field, Rotating cloud, Faradic current, Charge and discharge*.

1. INTRODUCTION

Lightning is a sudden electrostatic discharge occurring between the charged regions of a cloud (intra-cloud lightning, IC lightning), between two clouds (CC lightning), or between a cloud and the ground (CG lightning). The strong electric field built between the charged regions can breakdown the air, and so form a discharge channel. In this process the created light is called flashes, and the produced powerful shock wave from the explosively expanded air caused by nearly instantaneous heating is heard as thunders [1, 2].

Many researchers have early explored the charging mode of particles in a cloud, and the typical ones include ice-crystal collision mode [3, 4,5], temperature difference mode [1,6], icing charging mode [7, 8], and so on. These modes are basically related with the collision of particles in a cloud, and they point out that it is the colliding between these particles that induces the occurring of positive or negative charges in clouds. Many literatures have also discussed the mechanisms of lightning formation, in which the collision charging mechanism of intra-cloud particles is a common explanation [1, 9,10]. The mechanism means that the collision- induced charges among the cloud particles (droplets and ice crystals, etc.) in the cumulonimbus cloud and the precipitation particles (rain, snow, graupel and hail, etc.) move in separating trend, meanwhile these motions are mutually restrained by the Coulomb interaction. However the updrafts lifting cloud particles and the gravity acting on precipitation particles can offset the interaction, leading to the separation of the positive and negative charges. Consequently, the lighter positive-charged ice crystals are carried upward to the top of the cloud, and the bigger-diameter negative-charged graupels sink to the bottom of the cloud. When the charges are accumulated to a certain quantity, the strong electric fields can be built between different parts in a cloud or between the cloud and the ground, even the field intensity can reach averaged to some KV/cm, and partial region can reach high to 10,000 V/cm. Such strong electric fields are enough to breakdown the atmosphere inside and outside the cloud. In these circumstances, the lightning between different parts of a cloud, different clouds, or between the cloud and the ground are formed [11].

Some investigations show that the warm-front thundercloud caused by the convergence of warm and cold drafts does not meet the forming conditions of ice-crystal particles, and in most cases the tornado thunder, so-called cyclonic storm, and the thunderbolt mixed in the intense updrafts produced in volcanic eruptions have also no component of ice crystal particles [12]. Yet, the friction of air participated is the foundation of charge development and separation process [5]. As for how to accumulate the separated charges, the related literatures have not given further descriptions. However for their directional accumulation, Tangshan [13,14] has given an explanation in a short essay. He think when the cloud with great deal of positive and negative charge particles moves rapidly eastwards or westwards horizontally (the maximum of the wind speed can be up to 40m/s), it cuts the geomagnetic field lines, just like a conductor cutting magnetic line to produce electric current. So the directional movement of the positive and negative charges in cloud happens, with the moving direction being predicated by the right-hand rule. Consequently, more and more positive and negative charges will accumulate on the top and the bottom parts of the cloud, respectively, which creates the condition for lightning occurrence. The works above analyze the forming mechanism of thundercloud charge and the producing process of lightning from different aspects. However because the processes of charge separation and accumulation have not been understood completely up to now, and the relative unpredictability of lightning also limits the complete explanation of how or why it occurs, the mechanism that causes the charges to build up to lightning are still a matter of scientific investigation. Here we make an exploration for the lightning formation starting from the interaction between the geomagnetic field and rotating cloud or volcanic ash. The paper is arranged as follows. The second part introduces the fundamental principle of electromagnetic induction and an experiment designed to test the charge moving in a coil induced by geomagnetic field. Sec. 3 makes analyses about the movement of high-speed rotating cloud using the theory of electromagnetic induction, and about the process of charge separation and accumulation in a cloud under the geomagnetic field. In the last part of the paper, the research conclusions are outlined.

2. Fundamental theory and an experiment

2.1 The theory of electromagnetic induction

According to the Farady law of electromagnetic induction [15], an alternating magnetic field can produce an electric field, and induce in an exposed conductor the electromotive force denoted by

$$\varepsilon = -\mathrm{N}\frac{\mathrm{d}\Phi}{\mathrm{d}t}, \qquad (1)$$

Where N is the coil turns, Φ the magnetic flux in the coil. When a conductor moves in a static magnetic field, the magnetic flux is also changing relative to the conductor. In this case, the motional electromotive force induced in the conductor can be expressed by

$$\varepsilon = \int_L (\vec{v} \times \vec{B}) \cdot d\vec{l}, \qquad (2)$$

In which $\vec{B}$ is the intensity of magnetization, $\vec{v}$ the velocity of the conductor cutting magnetic field lines, and L the effective length of the conductor. The direction of the motional electromotive force can be determined by the right-hand rule.

According to the Ampere's law [15], the Ampere force on a given current-carrying wire in a magnetic field can be described by

$$F = \int_L Id\vec{l} \times \vec{B}. \qquad (3)$$

In a uniform magnetic field, if the current-carrying wire, with the current I and length L, is perpendicular to the direction of the magnetic field $\vec{B}$, the Ampere force on the wire can be written conveniently as

$$F = IBL, \qquad (4)$$

And its direction can be predicated with the left-hand rule.
Below we shall illustrate, based on an experiment, how the motional electromotive force is given by the conductor cutting geomagnetic line, and how the charges are accumulated. Through analyzing the movement of high-speed rotating cloud under the geomagnetic field, we can explain the directional accumulation in the process of the charge separation.

2.2 An experiment

Many hypotheses on lightning are only built on the theories. Here based on the principle of electromagnetic induction, we designed an experiment to demonstrate a conductor can produce the motional electromotive force by cutting geomagnetic field lines, and thereby simulate the high-speed rotating cloud or volcanic ash can also cut geomagnetic lines so as to produce, accumulate charges and discharge.
According to the theory of electricity generator [16], a hollow coil of 30 cm long and 12 cm wide was wound with a copper wire, the turn number of which was about 120. In the experiment, this hollow coil was put in the geomagnetic field as shown in Fig. 1, the diode was a Ge transistor, and its break-over voltage was relatively low with about 0.35 V. Limited by the mechanic condition and due to the large vibration caused by coil's rotating, the maximal rotating speed was about 2272 rpm (Tab. 1)

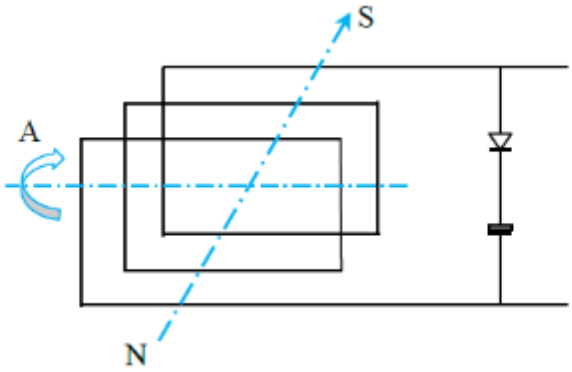

Fig. 1 Schematic diagram to generate electricity using geomagnetic field (A-rotating direction of the coil; N,S-two poles of the geomagnetic field)

Talbe 1 Experimental data of a hollow coil cutting geomagnetic field lines to produce motional electromotive forces

items	data						
Turn number	120 for all						
Coil area(cm^2)	360 for all						
Direction of rotating axis	Horizontal direction of East and West						
Running time with stable velocity(min)	5 for all						
Rotating velocity (rpm)	568	852	1136	1420	1704	1988	2272
Measured voltage of capacitance (mV)	55	115	172	229	287	359	378

The experiment showed that the voltage of the capacitance increased with the increase of rotating speed, and when the rotating speed was up to 2272 rpm, the voltage of the capacitance can be up to about 0.378 V. If the break-over voltage of the diode 0.35 V was added, the peak electromotive force produced by the human-driven rotating of the experimental coil in the geomagnetic field was nearly to 0.728 V. So we concluded that the copper winding coil, as a conductor, can produce the motional electromotive force by cutting the geomagnetic field lines.

3. Analysis of charge moving in the high-speed rotating cloud

The high-speed rotating cloud is a strong air vorticity, which is produced by the strong convective motion of the air in an extremely unstable weather condition [17]. The axial of the rotating cloud may be horizontal (the convergence of cold and warm air currents) and vertical (tornadoes), and the intense updrafts produced in volcanic eruptions can also drive the volcanic ash cloud rotate with high speed along the horizontal axis. Due to the influence of the centrifugal force, the water droplets or ice crystals contained in peripheral rotating cloud are with higher densities and so lower break-down voltages, they are equivalent to the conductors. Suppose the rotating cloud was divided into several cross sections along the axis, each of which had definite thickness. The section in rotating was equivalent to a closed conductor cutting magnetic lines in geomagnetic field (Fig. 2).

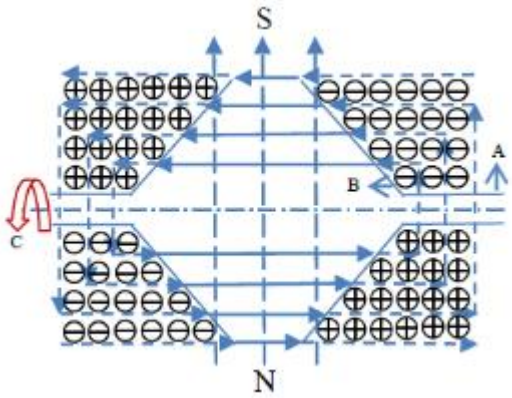

Fig. 2 Discharge principle for convective air mass (A-charging interface; B-interface of the convective air mass and the stable cloud; C-rotating direction of the convective air mass; N and S are two poles of geomagnetic field)

According to the electromagnetic induction theory, when a closed coil rotates in a magnetic field and cuts the field lines, the Faradic current can be produced in it. Similarly, when the axis line of an intense convective air mass is horizontal, the electrifying and charging processes of the horizontal section plane passing through the axis line can be analyzed as in Fig. 2, in which the solid line with arrow is the moving direction of positive charges in a rotating cloud, and the dashed line with arrow is the direction of charging current in a relatively stable cloud. The stable cloud can be polarized under the induction electric field, which is equivalent to a capacitor whose positive pole carries positive charges (electron holes) and the negative pole carries negative charges (electrons). The charging voltage of stable cloud is the motional electromotive force of single sided conductor with voltage $\varepsilon/2$.

Above analysis is to the horizontal section along the axis line. Similarly, any section along the axis can be regarded as a layer of charge-discharging circulation, and the electromotive force also changes as a cosine function with the dihedral angle of the section and the horizontal plane. For different dihedral angles, the initial phase is also different (Fig. 3).

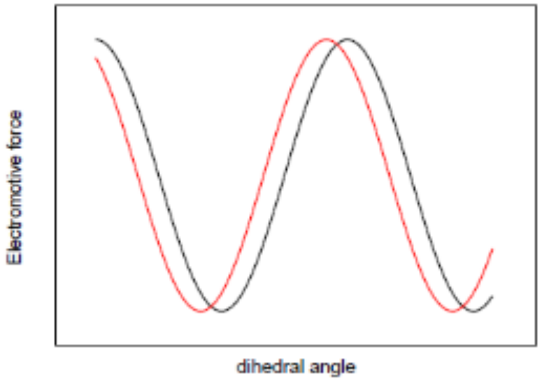

Fig.3 Change of the electromotive force with angle between the section and the horizontal plane (θ is the initial dihedral angel)

The existence of a relatively stable cloud is the necessary condition for charging realization. Due to the centrifugal force, the rotating cloud forms the convective cloud of fusiform. Fig. 4 is the horizontal section of the convective cloud. Evidently the central part of the section is with a higher rotating velocity, and there is a slowing down

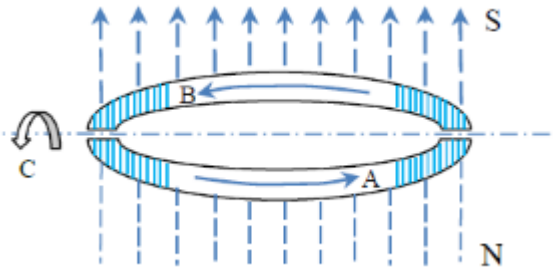

Fig.4 Schematic diagram of the convective cloud producing Faradic current (A, B-direction of Faradic current; C-rotating direction of the convective cloud; N, S-two poles of geomagnetic field)

Tendency at other parts towards two ends. Because it cuts the geomagnetic lines, according to the right-hand rule, the Faradic current can be formed through the movement of charges as shown in Fig. 4.

The existence of Faradic current makes the cloud produce a force opposite to the rotating direction, according to the left-hand rule, and this force can keep a balance with the pushing force acted on the rotating draft and form a relatively stable region, as shown in the shaded portion of Fig. 4. It is just this stable region that creates the charging condition, finishes the charge build up at both the positive and negative poles, and forms the clouds with the positive and negative charges, respectively. In Fig. 2 we can also find a vertical and longitudinal contact face between the convective air mass and the stable cloud. When the charging voltage rises to some extent, the breakdown discharging will take place in between two electrodes, which is the so-called lightning phenomenon. Depend on different directions of cloud shifting driven by wind, it can be intra-cloud lightning or inter-cloud lightning [18].

The balance of the relative stable region in the shaded portion of Fig. 4 is easy to be broken down, and what is more, this region will shift under the influence of air draft. The existence of this metastable region can also be used to interpret some bewildering phenomena, such as the different shapes of lightning and the formation of ball lightning [19]. In these analyses, we suppose the axis line direction of the convective air mass is horizontal. The same effect can be generated when the axis line of the convective air mass is perpendicular to the ground surface, e.g., the lightning induced by hurricanes.

Similarly in the process of volcanic eruption, due to the impact of the follow-up air draft erupting with high speed, the cloud generated from volcanic ash forms a rapidly rotating convective air mass [20]. Because of the influence of centrifugal force, the outer layer volcanic ash in convective air mass is with high density distribution and good conductivity, so the Faradic current can be easily produced under the geomagnetic field. In the same way, the existence of the Faradic current make the rotating air mass in the geomagnetic field be imposed a force with the direction being opposite to the rotating direction. As a result, the two ends of the rotating air mass are with lower rotating velocity, and form the relatively stable regions, which is the necessary condition to finish the charging process.

4. Conclusions

In this paper we give a simulation analysis to the cause of lighting induced from high-speed rotating cloud and volcanic ash, based on the electromagnetic induction law and combined with an experiment designed. It is pointed out that the existence of the geomagnetic field is one of the necessary conditions to generate lightning, and that the high-density distribution of droplets, ice crystals, or volcanic ash contained in the outer layer of high-speed rotating air mass, which makes it with good conductivity, is also the indispensable condition of inducing lightning. The existence of relative stable region in the process of cloud rotating is the key factor of charge generation and accumulation. At stable regions of the rotating cloud, the accumulation of the induced charges, generated by the high-speed rotating cloud cutting the geomagnetic lines, creates the sufficient condition for lightning occurrence. The conclusions obtained here can primely guide interpreting other types of lightning generation.

Acknowledgement

This work was supported by National Natural Science Foundation of China (grant 11674198).

References

[1].Dwyer JR, Uman MA. The physics of lightning, Phys. Rep. 2014; 534(4):147-241. Available at: https://www.sciencedirect.com/science/article/pii/S037015731300375X

[2].Yang YH, Li JC. Lightning forming principle and defense measures of lighgning disaster, J. Agric. Catastro. 2014: 4(12): 47-49. Available at: https://www.taodocs.com/p-87161039.html

[3].Akinyemi ML, Boyo AO, Emetere ME, Usikalu MR, Olawole FO. Lightning a fundamental of atmospheric electricity, IERI Procedia. 2014; 9: 47 – 52. Available at: https://www.sciencedirect.com/science/article/pii/S2212667814000872

[4].Simpson GC, Robinson GD. The distribution of electricity in thunderclouds, Proc. Roy. Soc. 1941; 177(970): 281-329. Available at: https://royalsocietypublishing.org/doi/abs/10.1098/rspa.1941.0013

[5].Petersen D, Bailey M, Beasley WH, and Hallett J. A brief review of the problem of lightning initiation and a hypothesis of initial lightning leader formation, J. Geophys. Res. 2008;113: D17205. Available at: https://www.onacademic.com/detail/journal_1000035760675610_0f3c.ht ml

[6].Reynolds SE, Brook M, Gourley MF. Thunderstorm charge separation, J. Atmos. Sci. 1957;14(5): 426-436. Available at: http://xueshu.baidu.com/usercenter/paper/show?paperid=bf79cb9f53d006 e4ccbbba9077db4625&site=xueshu_se

[7].Babich LP, Bochkov EI, Neubert T. The role of charged ice hydrometeors in lightning initiation, J. Atmos. Sol.–Terr. Phys. 2017;154: 43–46. Available at: http://xueshu.baidu.com/usercenter/paper/show?paperid=02969100a269a f8df3824b3bb47daa12&site=xueshu_se

[8].Berdeklis P, List R. The ice crystal–graupel collision charging mechanism of thunderstorm electrification, J. Atmos. Sci. 2001;58(18): 2751-2770. Available at: https://www.docin.com/p-259546742.html

[9].Takahashi T. Riming electrification as a charge generation mechanism in thunderstorms, J. Atmos. Sci. 1978; 35:1536-1548. Available at: http://xueshu.baidu.com/usercenter/paper/show?paperid=b3c18d9bddb625809da4c44da26824cd&site=xueshu_se

[10]. Gharaylou M, Pegahfar N, Bidokhti A. Electrical charge transfer modeling(lightning) in cloud and its implementation in a one-dimensional prognostic cloud model, J. Earth and Space Phys. 2014; 40(1) : 137-148. Available at: http://xueshu.baidu.com/usercenter/paper/show?paperid=113f3a19769cd9 a4aa6a979354dfa4c2&site=xueshu_se
[11]. Mazur V, Ruhnke LH. Qualitative overview of potential, field and charge conditions in the case of a lightning discharge in the storm cloud//Heinz-Wolfram Kasemir: His collected works. American Geophysical Union, 2013. Available at: http://xueshu.baidu.com/usercenter/paper/show?paperid=169bcc740c543f 6bfb3fcc0c82dbe061&site=xueshu_se
[12]. Zheng D, Zhang YJ, Meng Q, Lu WT, Zhong M. Lightning activity and electrical structure in a thunderstorm that continued for more than 24 h, Atmos. Res. 2010; 97(1-2): 241-256. Available at: https://www.researchgate.net/publication/229364583_Lightning_activity_ and_electrical_structure_in_a_thunderstorm_that_continued_for_more_th an_24h
[13]. Tangshan Q. Surveying into the formation of lightning, High Voltage Eng. 1988; (2): 86-87 (in Chinese). Available at: http://xueshu.baidu.com/usercenter/paper/show?paperid=6b21d6f2801ef88afc17ced84419d2d5&site=xueshu_se
[14]. Zhou ZM, Ji AH. Practical technology of modern lightning protection. Electronic Industry Press, Beijing, 2015 (in Chinese). Available at: https://www.amazon.cn/dp/B0771KNRRC
[15]. Sengupta DL, Liepa VV. Applied Electromagnetics and Electro- magnetic Compatibility. Wiley Interscience, Hoboken, 2005. Available at: https://onlinelibrary.wiley.com/doi/book/10.1002/0471746231
[16]. Wildi T. Electric Machine, Drives, and Power System. 4th ed, Prentice Hall, New York, 2000. Available at: https://www.amazon.com/gp/product/0130824607
[17]. Holton J R, Curry JA, Pyle JA. Encyclopedia of Atmospheric Science. Academic Press, London, 2003. Available at: http://xueshu.baidu.com/usercenter/paper/show?paperid=6a89ab2a122c0666aa375a2680562d19&site=xueshu_se
[18]. Cooray V. Mechanism of the Lightning Flash, in: The Lightning Flash, 2nd ed., V. Cooray (Ed.), the Institution of Engineering and Technology, London, 2014. Available at: http://xueshu.baidu.com/usercenter/paper/show?paperid=fe79e3abbcf759101b7a4b271b2e7900&site=xueshu_se
[19]. Ball P. First spectrum of ball lightning. Physics Online Journal, 2014, 7. Available at: http://xueshu.baidu.com/usercenter/paper/show?paperid=4e871c41788db edc4f8ad0181df7bf5f&site=xueshu_se
[20]. Bennett AJ, Odams P, Edwards D, Arason P. Monitoring of lightning from the April–May 2010 yjafjallajökull volcanic eruption using a very low frequency lightning location network, Environ. Res. Lett. 2010; 5 (4): 044013. Available at: http://xueshu.baidu.com/usercenter/paper/show?paperid=df02811d9f7a49 b2d15a28c630ca55e0&site=xueshu_se