Abnormal Increase of the Electrical Conductivity of the Atmosphere near the Ground Caused by Thunderstorms

By H. Hatakeyama

Meteorological Research Institute, Tokyo, Japan

and M. Kawano

Electro-Technical Laboratory, Tokyo, Japan

(Manuscript received 31 May 1957)

Abstract

Several authors observed an abnormal increase of the electrical conductivity of the atmosphere near the ground during a thunderstorm.

It is considered that the abnormal increase of conductivity is due to the natural radioactivity (RaB and RaC) captured by rain drops. The β -ray irradiation of RaB and RaC produces small ions in the atmosphere near the ground. They contribute to the abnormal increase of the electrical conductivity of the atmosphere near the ground. We estimated the production of small ions by using the observed value of the electrical conductivity of the atmosphere. Then by radiological treatment we estimated the quantity of RaB and RaC brought down by the thunderstorm rain.

For the thunderstorm rain of August 3, 1941, it was estimated at several hundred times of 10^{-13} curie per cm^2 of the earth's surface. An observed value of the intensity of radioactivity of thunderstorm rain is $50\sim 300 \times 10^{-13}$ curie/cc. The value estimated by us is in good coincidence with the observed value.

1. Introduction

An abnormal increase of the electrical conductivity or the number of small ions in the atmosphere near the ground during a thunderstorm was observed by Hatakeyama (1946), Norinder and Siksna (1950), Siksna (1951) and Kikuchi (1954). The increase occurs abruptly as soon as a thunderstorm shower begins to fall. When it has passed away, the conductivity or ionic density makes an exponential decrease, and the time to recover the normal value is about two hours. Wait and McNish (1934) observed that the production of ion pairs in the atmosphere during the thunderstorm is proportional to the amount of rainfall. It is clear that this is due to the radioactivity (principally β -ray) of thunderstorm rain.

In the present paper, the authors intend to discuss the radioactivity of thunderstorm rain from the viewpoint of atmospheric

electricity by using the observational material of the electrical conductivity of the atmosphere near the earth's surface taken by Hatakeyama (1946) at Maebashi Weather Station ($139^{\circ}04'E$, $36^{\circ}24'N$).

2. Results of observation

In the summer of 1941, we participated in a thunderstorm research programme conducted in the neighbourhood of Maebashi. The observation of the electrical conductivity of the atmosphere using the Gerdien's apparatus was in the programme. Visual observation was made semi-hourly or quarter-hourly. General results are as follows.

(i) The normal value of the electrical conductivity of the atmosphere was within $0.1\sim 0.3 \times 10^{-4}$ E.S.U. and the mean value was around 0.2×10^{-4} E.S.U.

(ii) When thunderstorm occurs, the positive and negative partial conductivity

increase suddenly. The speed of increase of the negative partial conductivity was greater than the positive.

(iii) After reaching the maximum value, both positive and negative partial conductivities showed exponential decrease. Its half-value period was about one hour.

(iv) The maximum value of the positive partial conductivity was 0.88×10^{-4} E. S. U. and that of negative was 2.01×10^{-4} E. S. U., both in August 3.

Results of observations in August 3, 1941, are shown graphically in Fig. 1. As will be seen clearly in the figure, the negative partial conductivity suddenly increases to

Fig. 1.

the maximum value at 17 h. The positive partial conductivity reaches the maximum value at 18 h, one hour later than the negative. The record of rainfall at Maebashi Weather Station is as follows.

● 16 h 37 m — ● 16 h 38 m — ● 16 h 42 m —
 ● 16 h 53 m — ● 16 h 56 m — ● 17 h 21 m —
 ● 17 h 50 m — 18 h 25 m.

Amount of rainfall, 16 h—17 h 0.7 mm,
 17 h—18 h 32.9 mm. 18 h—19 h 1.8 mm,
 total 35.4 mm.

3. Discussions

The natural radioactivity of rain water is due mainly to RaB and RaC captured by raindrops through their journey from a rain-making layer in cloud. The production of small ions in the atmosphere near the ground is caused by β -ray irradiation from them.* Radioactive substances brought by rain water are considered to be distributed uniformly on the earth's surface. Within the range of β -ray, the relation between the rate of ion pair production and the number of small ions in the atmosphere is calculated by the equation of ionization equilibrium.

In a condition of ionization equilibrium when there exist small and large ions concurrently,

$$q = \alpha n^2 + \beta N n \quad (1)$$

where q is the rate of ion pair production by ionization, n and N is the number of small and large ion respectively. On the other hand we have a following relation between the electrical conductivity λ and the number of small ions,

$$\lambda = n e k \quad (2)$$

where k is the mobility of small ion. Substituting (2) into (1) we have

$$q = \alpha \left(\frac{\lambda}{e k} \right)^2 + \beta N \frac{\lambda}{e k} \quad (3)$$

At Maebashi we have no observational data on N but the value of N is considered to be large because the observed electrical conductivity of the atmosphere is relatively small. We assume $N = 2 \times 10^4$ and does not change during a rainfall. Then we can calculate the rate of ion pair production q by equation (3) in place of the electrical conductivity. The value of q is shown in the right-hand-side of Fig. 1.

When there is a radioactive substance Q (curie) on a unit area of the earth's surface

* The rate of ion pair production by γ -ray is a few percent of that by β -ray in the mean energy of RaB and RaC.

and its surface density is uniform all over the earth, the number of ion pairs produced by β -ray radiated from Q in a unit volume of the atmosphere at height d above the earth's surface is calculated by the following procedure (cf. Fig. 2).

Fig. 2.

At first, the number of β -particles N_e passing through the reference unit volume P in the atmosphere is as follows,

$$N_e = 3.7 \times 10^{10} \times \int_0^\infty Q \cdot 2\pi r \cdot dr \cdot e^{-\mu\sqrt{r^2+d^2}} \cdot \frac{\Delta\phi}{4\pi}, \quad (4)$$

where μ is the absorption coefficient of β -ray by the atmosphere and $\Delta\phi$ is the solid angle. By simple geometrical calculation we get,

$$\Delta\phi = \frac{\pi a^2}{r^2 + d^2} \quad (5)$$

where a is the radius of the unit volume. Substituting (5) into (4),

$$N_e = 3.7 \times 10^{10} \times \frac{Q\pi a^2}{2} \int_0^\infty r \cdot dr \cdot e^{-\mu\sqrt{r^2+d^2}} \cdot \frac{1}{r^2+d^2}. \quad (6)$$

Putting $r^2 + d^2 = x^2$, we get

$$N_e = 3.7 \times 10^{10} \times \frac{Q\pi a^2}{2} \int_d^\infty \frac{e^{-\mu x}}{x} dx. \quad (7)$$

The number of ion pairs I_e produced by β -ray along a trace of a unit length is as follows,

$$I_e = 46 \times \left(\frac{c}{v}\right)^2 \quad (8)$$

where c is the light velocity and v is the velocity of β -ray. So the rate of ion pair production in a unit volume of the atmosphere is expressed as follows,

$$q = 46 \times \left(\frac{c}{v}\right)^2 \times 3.7 \times 10^{10} \times \frac{Q\pi a^2}{2} \int_d^\infty \frac{e^{-\mu x}}{x} dx. \quad (9)$$

If we take 500KeV for the mean energy of β -ray spectrum of RaB and RaC,

$$\frac{c}{v} = 1.16 \quad \text{and} \quad \left(\frac{c}{v}\right)^2 = 1.35. \quad (10)$$

The absorption coefficient μ of β -ray is not constant like that of the light or γ -ray but is a function of the distance x from the radioactive source Q . We get the value of the integral in the equation (9) by numerical integration, assuming constant absorption coefficient

$$\bar{\mu} = \frac{1}{R} \int_0^R \mu dx = 0.017E^{-1.43} \text{ cm}^2/\text{mg}^2$$

where R is the range of β -ray and E is the maximum energy of β -particle in MeV.

We can calculate the value of Q by the equation (9) using the value (3), (10) and the above numerical value of the integral.

The quantity of RaB and RaC brought down by the thunderstorm rain of August 3, thus estimated, is 377×10^{-13} curie per cm^2 of the earth's surface when we take the height of the reference unit volume above the ground is 5 cm and 941×10^{-13} when it is 10 cm both corresponding to the maximum value of $q=80$ J. Our observation of electrical conductivity of the air was made at a few meters above the ground and we consider the electrical state of the air is uniform between these heights and several centimeters above the ground by eddy diffusion.

Kamada and Ōnishi (1956) in Kagoshima observed that the insensity of radioactivity of thunderstorm rain is $50 \sim 300 \times 10^{-13}$ curie/cc.

Besides the occasion of thunderstorm of August 3, we have a few examples of observation of the electrical conductivity of the atmosphere during the thunderstorm rainfall. Observed values of λ_- and estimated values of q and Q are tabulated in

Table 1. Seeing Fig. 1 and Table 1, we may conclude that the principal part of the abnormal increase of the electrical conductivity of the atmosphere is due to the radioactivity of the thunderstorm rain.

Table 1.

Date	λ_- (E. S. U.)	q	Q (curie/cm ²)		Amount of rainfall
			$d=5$ cm	$d=10$ cm	
July 27	1.70×10^{-4}	68 J	320×10^{-13}	800×10^{-13}	3.3 mm
August 3	2.01	80 J	377	941	35.4
„ 7	0.57	22 J	104	259	0.0
„ 10	0.75	30 J	141	353	2.7

References

- 1) **Hatakeyama, H.** 1946: Report of the observation of atmospheric electricity during the thunderstorm near Maebashi in the summer, 1941. *Kishōgijitsukan-yōseijo Kenkyūhōkoku*, **1**, 33-54 (in Japanese). —2) **Kamada, M. and T. Onishi** 1956: The occurrence of an unusually high-level artificial radioactive rainfall in the area of Kagoshima, Japan, since May 14, 1954. *Research in the Effects and Influences of the Nuclear Bomb Test Explosions*, **1**, 161-175. —3) **Kikuchi, S.** 1954: The continuous registrations of the atmospheric small-ion contents at Kakioka and some relations to the meteorological elements. *Memoirs of the Kakioka Magnetic Observatory*, **1**, 55-74 (in Japanese with English Abstract). —4) **Norinder, H. and R. Siksna**, 1950: The measurements of the variation characteristics of the density of small-ions. *Arkiv för Geofysik*, **1**, 1-32. —5) **Siksna, R.** 1951: Variations of large-ions in atmospheric air during disturbed weather conditions. *Arkiv för Geofysik*, **1**, 237-246. —6) **Wait, G. R. and A. G. McNish** 1934: Atmospheric ionization near the ground during thunderstorms. *Mon. Wea. Rev.*, **62**, 1-4.