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# Electrical conductivity of Nor'wester rain water

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ABSTRACT. Electrical conductivity of samples of rain water from some pre-monsoon thundershowers were measured. It is observed that conductivity gradually decreases with the progress of rain, passes through a minimum and rises again towards the end. It is also noticed that during the period of its rise, conductivity shows an inverse relationship with the intensity of rain of the form $K \propto I^{-n}$ where $n$ is a positive fraction. The conductivity of rain water towards the end of a thundershower may be higher than that in the beginning.

The time variation conductivity has been explained by considering (a) the dissolution of pollutants in cloud droplets in cumulus stage, (b) the addition of pollutants to rain by washing out mechanism, (c) concentration of pollutants in droplets formed in the updraught and (d) introduction of environmental air in the cloud field at the dissipating stage.

## 1. Introduction

Meteorological aspect of the mechanism of nor'westers of Bengal have been the subject of many investigations (Desai and Mal 1938, Desai 1950, Newton 1951). The study of electrical conductivity which is proportional to the total concentrations of dissolved substances (which are normally electrolytes) may help us in understanding the physical processes associated with it. With this in view the present study was taken up during the pre-monsoon season of 1958.

The collection of rain water and measurement of conductivity were conducted inside Barrackpore Aerodrome and near Barrackpore Observatory. Except for an enamel factory at a distance of about 500 metres, there is no major source of pollution within 2 km of the site of collection. The vegetation of this area is rather thick. Outside this there are many factories to the north as well as to the south. In fact the aerodrome is situated within the industrial area of Calcutta and is about 16 miles to the north of the city.

The methods of collection and measurement of rain water have been described by the author (Mukherjee 1958) and are not being described here. For the present study a big Royal Berlin porcelain basin was used for the collection of water. Measurements of conductivity were done immediately after the collection of water. The conductivity instrument and the cell and all other glass apparatus used in this experiment were obtained on loan from the Jadavpur University for short periods. The conductivity water used in this experiment was supplied by the Jadavpur University regularly. This water was stored in polythene bottles.

## 2. Data

In the previous communication (Mukherjee 1958) the conductivities of all types of rain water collected during the monsoon of 1955 were reported. In this study though water from all types of showers were collected only the data for thundershowers will be reported.

Although the last half of April falls within the nor'wester season, there were no nor'westers for which the data could be obtained in April 1958. The thunderstorm approached the station from southwest to west and were not accompanied by any squall in the cases during this month. Only on 27 April a southwesterly squall of 23 kt was recorded.

2.1. *Meteorological conditions*—As we studied the changes in conductivity of rain water in individual thundershowers it will be of interest to know the meteorological

conditions associated with each thundershower. In May 1958, we had conductivity measurements on 5th to 7th and in June we had on 6th and 9th.

On 5 May, south to southwesterly gusty surface wind was blowing from the morning, the average speed remained between 10–15 kt. One to two octas of altocumulus moving from northwest and one to two octas of cumulus clouds could be seen from the morning. At about 1630 IST cumulonimbus cloud was observed near the northwestern horizon. Thunder was heard at 1740 IST. The cloud developed rapidly between 1630 and 1730 IST and by 1800 IST the sky was overcast. The thundershower commenced at 1820 IST and ceased at 1855 IST. A northwesterly squall passed over the station at 1838 IST, when the maximum speed reached 42 kt. The surface wind was southsouthwesterly before the squall and became southwesterly after the shower. The temperature fell by 8°C and pressure rose by 4·5 mb. The sky was clear after the thundershower.

On 6 May, the initial conditions were nearly the same as those for the 5th. The wind was south to southwesterly, 10–15 kt and was gusty. Cumulonimbus cloud was seen at about 1730 IST and thunder was heard at 1820 IST. At the same time a northwesterly squall of 35 kt was passing over the station. Surface wind remained northwesterly, gusty with an average speed of 30 kt upto 1900 IST and changed suddenly to southeasterly 5–10 kt afterwards. The thundershower started at 1840 IST. Thunder continued till 1920 IST and the shower stopped at 1928 IST. The sky remained overcast with altostratus cloud and lightning was visible on the southeastern side. At 1930 IST light intermittent rain started and continued upto 2040 IST. Collection of water was stopped at 1928 IST, restarted at 1930 IST and continued upto 2030 IST. During the last ten minutes only 8 cc of water could be collected and it was not sufficient for measurement of conductivity. For the purpose of the present study, water collected upto 1928 IST was taken to be from thundershower. The sky cleared long after the cessation of rain. Due to the nor'wester, temperature fell by 9°C and pressure rose by 4 mb.

As on previous days, the thunderstorm approached the station from northwest on 7 May but was mild as observed from Barrackpore observatory. A thundershower started at 1726 IST and stopped at 1743 IST but the amount of rainfall was too little. Another shower followed at 2018 IST and stopped at 2053 IST. Thunder continued upto 2220 IST. Water samples were collected from this last rain. The temperature fell by 5°C and pressure rose by 3 mb due to the thunderstorm.

On 6 June, the surface wind was south to southeasterly 4 to 9 kt throughout the day. The day was generally cloudy. Cumulonimbus cloud was seen to be approaching the station at 1830 IST from west. Thunder was heard at 1925 IST when a westerly squall of 52 kt passed over the station. Thundershower started at 1945 IST and continued upto 2018 IST. Water was collected upto 2010 IST as the rainfall afterwards was not sufficient for measurement of conductivity. Thunder was still continuing after the end of the shower and the sky remained overcast with cumulonimbus, stratocumulus and altocumulus clouds. Temperature fell by 7°C and pressure rose by 5 mb due to the passage of the thunderstorm.

On 9 June, south to southeasterly wind of 4 to 9 kt blew over the station for the whole day. Cumulonimbus cloud was noticed at about 1630 IST and the thunderstorm was seen to be approaching the station from northwest. The development of the cloud was very rapid. A northwesterly squall of 35 kt came over the station at 1715 IST. Wind continued to be gusty but the speed was gradually decreasing till 1820 IST when it changed suddenly and became easterly to southeasterly, 10–15 kt. Thundershower started at 1745 IST and continued upto 2100 IST. Rain water was collected upto 1850

**TABLE 1**

**Upper winds during May and June 1958**

| Date | Height (km) | | | | | |
|---|---|---|---|---|---|---|
| | 1·5 | 3·0 | 4·5 | 6·0 | 7·5 | 9·0 |
| 5 May | 220°/13 kt | 260°/08 kt | 280°/13 kt | 280°/34 kt | 270°/51 kt | 280°/56 kt |
| 6 May | 220°/13 kt | 260°/13 kt | 310°/12 kt | 270°/38 kt | 270°/43 kt | 260°/36 kt |
| 7 May | Observation failure | | | | | |
| 6 June | 160°/11 kt | 310°/04 kt | 320°/12 kt | 270°/07 kt | 240°/03 kt | 240°/12 kt |
| 9 June | 230°/07 kt | 340°/14 kt | 280°/05 kt | 150°/05 kt | 200°/04 kt | 360°/04 kt |

IST. Temperature fell by 8 °C and pressure rose by 4 mb due to the thunderstorm.

There were some more nor'westers in May and June but due to some unavoidable reasons experiments could not be performed. Although only a few observations were available during the present set of experiments on which analysis could be performed, it would be seen that they show some general trend of variation of conductivity.

Upper wind data for the dates just discussed are presented in Table 1.

2.2. *Conductivity data*—Temperature of the water samples were between 22 and 24 °C in all cases. Except for the rainfall on 20 April, on all other days the temperature varied within 1°C.

In Table 2 are given the conductivity data.

### 3. Analysis

In the present study, the conductivity measurements were made in order to get any information about different physical processes during thundershowers. The data for 14, 19 and 20 April do not give much scope for further analysis for this purpose.

It will be noticed from the rest of the data that the conductivities of different samples of same rainfall show some regular characteristics.

3.1. *Time variation of conductivity*—Fig. 1 shows the variation of conductivity with time for the rainfall of 5 and 6 May and 6 and 9 June 1958. The plot of conductivity against time shows the following general feature—

*Conductivity decreases with time, passes through a minimum and then increases as the rain continues*—The conductivity values for the samples collected during 1834 to 1837 IST of 5 May has been neglected for this analysis. There is some anomaly in this reading in comparison to the readings just before and after this one. This seems definitely to be due to some sort of entrainment of some environmental air during the course of the thunderstorm. Only during this shower we have a squall. The anomalous reading was observed just before the occurrence of squall.

It will be noticed from Fig. 1 that on some days the conductivity decreased linearly with time in the beginning. Without further experimental study it is not possible to know as to how often such characteristic can be observed.

3.2. *Variation of conductivity with amount of rainfall*—Curves were plotted for conductivity against total amount of rainfall and they showed sharp change in conductivity before and after the minima. If $K$ represents conductivity of the sample of volume $V$ during the time interval $t$, then

TABLE 2

| Date (1958) | Collected during (IST) | Interval ($t$) (min) | Amount collected ($V$) (cc) | Conductivity ($K$) (mhos) |
|---|---|---|---|---|
| | | | | $\times 10^{-5}$ |
| 14 April | 1900—1940 | 40 | 25 | 2·96 |
| 19 April | 1810—1855 | 45 | 20 | 7·69 |
| | 1855—1917 | 22 | 20 | 4·56 |
| | 1917—1940 | 23 | 10 | 4·56 |
| 20 April | 2202—2212 | 10 | 19 | 5·61 |
| | 2230—2300 | 30 | 12 | 7·66 |
| 27 April | 2025—2035 | 10 | .. | 1·78 |
| | 2035—2045 | 10 | .. | 1·12 |
| | 2045—2055 | 10 | .. | 0·99 |
| | 2055—2105 | 10 | .. | 0·93 |
| | 2105—2115 | 10 | .. | 0·96 |
| 5 May | 1820—1822 | 2 | 70 | 2·64 |
| | 1822—1825 | 3 | 100 | 2·31 |
| | 1825—1828 | 3 | 98 | 1·98 |
| | 1828—1831 | 3 | 100 | 1·64 |
| | 1831—1834 | 3 | 90 | 1·42 |
| | 1834—1837 | 3 | 55 | 2·31 |
| | 1837—1840 | 3 | 108 | 1·42 |
| | 1840—1845 | 5 | 110 | 1·67 |
| | 1845—1855 | 10 | 35 | 2·82 |
| 6 May | 1840—1843 | 3 | 68 | 2·64 |
| | 1843—1846 | 3 | 58 | 2·31 |
| | 1846—1849 | 3 | 118 | 1·83 |
| | 1849—1852 | 3 | 140 | 1·64 |
| | 1852—1855 | 3 | 180 | 1·50 |
| | 1855—1858 | 3 | 100 | 1·41 |
| | 1858—1908 | 10 | 50 | 2·57 |
| | 1908—1918 | 10 | 30 | 3·00 |
| | 1918—1928 | 10 | 25 | 3·15 |
| 7 May | 2018—2023 | 5 | 17 | 4·82 |
| | 2023—2028 | 5 | 22 | 1·55 |
| | 2028—2033 | 5 | 12 | 1·92 |
| | 2033—2043 | 10 | 15 | 2·10 |
| | 2043—2053 | 10 | 10 | 2·52 |
| 6 June | 1945—1948 | 3 | 92 | 2·03 |
| | 1948—1951 | 3 | 100 | 1·41 |
| | 1951—1954 | 3 | 104 | 1·18 |
| | 1954—1957 | 3 | 120 | 1·05 |
| | 1957—2000 | 3 | 54 | 1·30 |
| | 2000—2010 | 10 | 42 | 1·87 |
| 9 June | 1745—1750 | 5 | 58 | 3·17 |
| | 1750—1755 | 5 | 38 | 2·60 |
| | 1755—1800 | 5 | 32 | 2·20 |
| | 1800—1805 | 5 | 86 | 1·74 |
| | 1805—1810 | 5 | 128 | 1·24 |
| | 1810—1815 | 5 | 145 | 0·94 |
| | 1815—1820 | 5 | 138 | 1·03 |
| | 1820—1825 | 5 | 160 | 1·00 |
| | 1825—1830 | 5 | 112 | 1·20 |
| | 1830—1835 | 5 | 96 | 1·40 |
| | 1835—1840 | 5 | 58 | 1·58 |
| | 1840—1845 | 5 | 52 | 1·74 |
| | 1845—1850 | 5 | 23 | 2·35 |

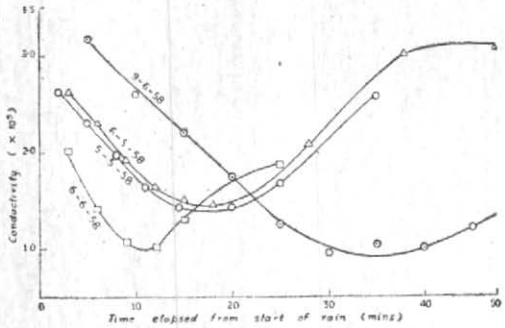


**Fig. 1. Variation of specific conductivity with time**

the total time elapsed from the start of rain will be denoted by $\Sigma t$ and the total volume of rain water will be $\Sigma V$. The conductivity of this total volume will be given by $\Sigma KV/\Sigma V$. This quantity when plotted against $\Sigma V$ or $\Sigma t$ will also show a variation of conductivity with volume or with time. In Fig. 2, such curves for $\Sigma KV/\Sigma V$ against $\Sigma V$ for 5 and 6 May and for 6 June are plotted. In these curves we find that the rate of decrease in conductivity is slow and that the minima are usually shifted towards the end. Seeing the nature of the curves, it was thought that log $(\Sigma KV/\Sigma V)$ against $\Sigma V$ may give some straight lines for the portion where $K$ is falling. It was only obtained for 5 May. On other days it is found that they are still curved and concave downwards.

3.3. *Salt brought down by rain : variation with time*—Rain water is usually pure. The concentrations of dissolved substances are low and may be said to be in infinite dilution in terms of electro-chemistry. Specific conductivity at infinite dilution is known to be directly proportional to the concentration of electrolytes. Although all the dissolved substances in rain water are not salts specially in an industrial area, it is customary to refer them as salt. Here also the term salt has been used to refer to all the dissolved substances.

$K$ is the conductivity and $\Sigma V$ is the volume of water collected during the time counted from the start of rain. The product $K \times V$ will be proportional to the total salt brought down by rain.

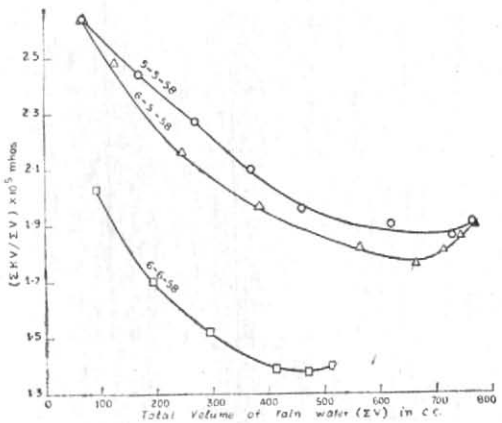


**Fig. 2**

Mordy (1953) measured the amount of combined nitrogen in rain water and observed that a plot of nitrogen against time lapsed from the start of rain will be a straight line.

In Fig. 3 are shown the graphs obtained by plotting $K \times V$ against time from start of rain for 5 and 6 May and 6 and 9 June. On 6 May, the graph is concave upwards upto the 9th minute, is straight line from the 9th to the 15th minute and is concave downwards upto the end. On 9 June, the graph is similarly concave upwards upto the 25th minute, is straight from the 25th to the 45th minute and is concave downwards upto the end. For 6 June the graph is a straight line upto the 12th minute and is concave downwards later. On 5 May, it is found that except for the first reading, the graph is practically straight line upto the 20th minute and is concave downwards later. The graph for 7 May was also plotted and was found to be concave downwards all the way.

The nature of these graphs seems to be qualitatively dependent on the intensity of the rainfall. When the rain starts and the intensity shows a marked tendency to increase, the water and along with that the amount of salt comes down in increased amount. When the intensity attains a more or less steady state, the curve becomes a straight line. Towards the end, the intensity of rain decreases sharply and so the amounts

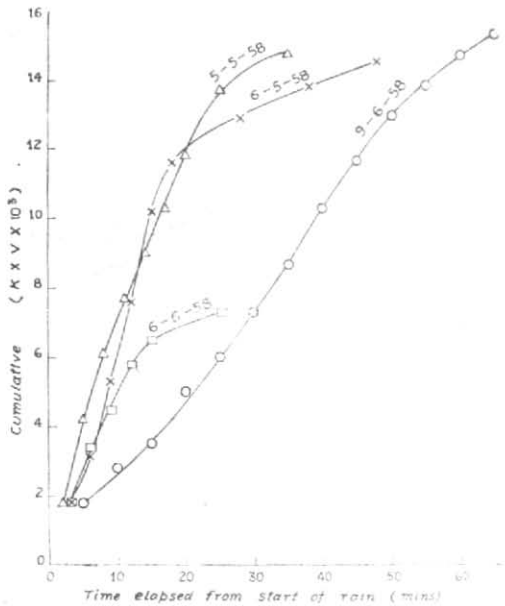


**Fig. 3. Variation of total deposition of salt with time**

of water and dissolved salt decrease. In cases where rain starts sharply and intensity remains practically constant for some time, the graph becomes a straight line in the beginning as has been observed on 5 May and 6 June.

3.4. *Deposition of salt by rain water*—In Fig. 4 are plotted $\Sigma KV$ against total rain for 5 and 6 May, and 6 and 9 June. As expected, these curves tend to converge at the origin. They are concave downwards in the beginning and concave upwards towards the end.

Comparing the curves for May and June, we find that the curves for May are above the curves for June thundershowers. This is probably due to the surface wind prior to the thunderstorm. On 5 and 6 May south to southwesterly wind of 10 to 15 kt blew for the whole day whereas on 6 and 9 June they were lighter. As the main city of Calcutta is to the south of the station, more salt were brought over the station on 5 and 6 May than on 6 and 9 June.

3.5. *Relationship between intensity and conductivity*—It has been observed that in a thundershower, when intensity gradually decreases before the end of rainfall and does not show any further increase, the conductivity shows a definite inverse relationship with it. It can be expressed as $K \propto I^{-n}$, where $I$ is the intensity of rain, and $n$ is a positive fraction. Fig. 5 shows such relationship for 5 to 7 May and 6 and 9 June. The value of $n$ varies between $+0{\cdot}26$ and $+0{\cdot}40$. Intensity of rain was not measured by any intensity raingauge. The volume of water collected per minute in the collecting vessel is proportional to the intensity of rain. This has been used here as intensity itself.

It has been shown by Best (1950) that the intensity of rain is related to the average radius of drops by the formula

$$r \propto I^{0{\cdot}232}$$

Therefore, we get $K \propto I^{-n} \propto r^{-n/0{\cdot}232}$

Similar relation was obtained by Turner (1955). The exponent of $r$ lies between $-1{\cdot}12$ and $-1{\cdot}73$. These values are in excellent agreement with Turner's results on freezing rain in Australia.

3.6. *Purity of water samples*—A sample of water having specific conductivity between 1 and $3 \times 10^{-6}$ mhos is termed as conductivity water. This is the purest water that can be obtained in a laboratory. In our investigation we find that water samples from these pre-monsoon thundershowers had conductivity between $0{\cdot}93 \times 10^{-5}$ and $7{\cdot}69 \times 10^{-5}$ mhos. They were, therefore, not very pure.

In the present study, it was noticed that visible impurities like dust particles were present in first fractions of rain water. As the rain continued, these solid substances gradually disappeared. Their absence gave a general belief that last fractions are pure. But conductivity data show conclusively that towards the end of a thundershower impurity in rain water increases. Water is sometimes more impure than what it was in the beginning.

## 4. Discussion

The conclusion mentioned in 3·1 above is most interesting and in the following paragraphs attempt will be made to explain it.

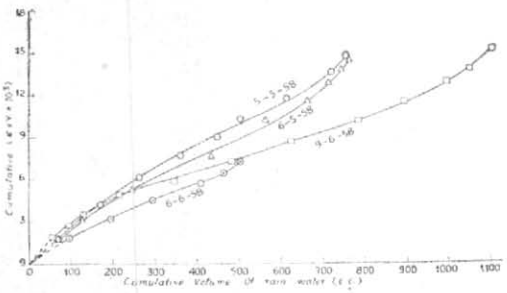

Fig. 4. Total deposition of salt against total volume of rain

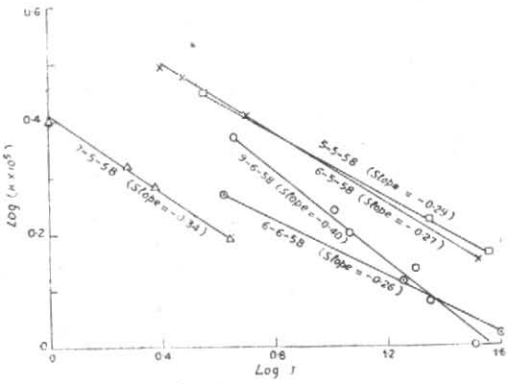

Fig. 5

Regarding the other interesting conclusion mentioned in 3·5, no satisfactory explanation could be obtained by the author.

The decrease and subsequent increase in salinity in rain from convective clouds was observed by Turner (1955). The explanation as proposed by Roy and Srivastava (1958) for such observation may be applicable for the present observation as well. Yet an alternative explanation is possible by considering gaseous pollutants to be the main contributing factor in the change in salinity in rain water in an industrial area which is given in the following paragraphs.

Soluble electrolytes in air are either in the form of very small particles floating in the air or in the gaseous state. They are removed by thundershower. Such removal starts from the start of the liquid phase and continues upto the end of the thundershower. Let us trace the life history of an idealised thunderstorm and try to understand how the removal of the soluble substances in air can take place during the different stages of its evolution. The life cycle of the thunderstorm has been described in accordance with the findings of the thunderstorm project (Byers and Braham 1949).

As thunderstorm is a product of vigorous convection, the pollution near the surface extends upto a great height and the air over a particular station to be visited by the thunderstorm would contain a uniform concentration of pollution. Since our measurements were near Calcutta only, where the air is full of combustion products, we shall assume that the soluble substances are mostly in the form of gases (like sulphur dioxide) emanating from the combustion of domestic and industrial fuels. This assumption has been made only to introduce simplicity in calculations.

4.1. *Cumulus stage*—The first stage of thunderstorm is the formation of a cumulus cloud. Condensation starts and continues until the commencement of thundershower. Let us now calculate the concentration of the pollutants dissolved in cloud particles.

It is well-known that the rate of condensation on a droplet of radius $r$ (assuming the density of water to be unity), is given by—

$$\frac{dm_r}{dt} = 4\pi K_1 r \triangle p \qquad (1)$$

where, $K_1$ = Diffusion coefficient of water vapour and

$\triangle p$ = Difference between ambient vapour pressure and that over the droplet.

Rate of dissolution of a gaseous pollutant is proportional to the surface area of the droplet in which it dissolves and the mass ($\mu$) of gas striking unit area due to the thermal motion of the molecules.

Thus $$\frac{dS_r}{dt} = A + 4\pi r^2 \qquad (2)$$

where $A = \text{or} < 1$

If $m_r$ denotes the mass of the droplet, then

$$m_r = \frac{4}{3}\pi r^3 \tag{3}$$

The concentration, of the dissolved gas in the droplet is given by

$$C_r = S_r/m_r \tag{4}$$

Therefore, $\frac{dC_r}{dr} = \frac{d}{dr}(S_r/m_r)$

$$= \frac{1}{m_r}\cdot\frac{dS_r}{dr} - \frac{S_r}{m_r{}^2}\cdot\frac{dm_r}{dr}$$

$$= \frac{1}{m_r}\left\{\frac{dS_r}{dt}\cdot\frac{dt}{dm_r}\cdot\frac{dm_r}{dr} - \frac{S_r}{m_r}\cdot\frac{dm_r}{dr}\right\}$$

From equations (1), (2), (3) and (4) we get

$$\frac{dC_r}{dr} = \frac{1}{m_r}\left\{\frac{A\mu 4\pi r^2}{4\pi K_1 \triangle p r} - C_r\right\}\frac{dm_r}{dr}$$

$$= \frac{3}{r}\left\{\frac{A\mu r}{K_1\triangle p} - C_r\right\}$$

$$= \frac{3A\mu}{K_1\triangle p} - \frac{3C_r}{r} \tag{5}$$

In the initial condition the concentration of pollutants in the air is large and so the value of $\mu$ is high. Again, we know that in the presence of sufficiently high concentration of nuclei, the condensation takes place even before the attainment of 100 per cent humidity. Under that condition the value of $\triangle p$ may be assumed to be very small. Thus in the initial condition of the formation of cloud particles, the first term on the right hand side of the equation (5) will be much greater than the second which as an approximation, may be neglected.

Then $$\frac{dC_r}{dr} = \frac{3A\mu}{K\triangle p} \tag{6}$$

Or $$C_r = \frac{3A\mu r}{K_1\triangle p} + a \tag{7}$$

where $a$ is a constant and assuming $\mu$ and $\triangle p$ to remain constant.

The equation (7) shows that when the cumulus cloud starts forming, the bigger particles become concentrated and the smaller particles dilute.

The cloud particles may enter into the process of rain formation immediately after they are formed or they may be remaining floating in air for some time without further development in size. The floating particles will still dissolve some pollutant from air in which it floats. The rate of dissolution of such pollutant is given by equation (2). The rate of change of concentration is

$$\frac{dC_r}{dt} = \frac{d}{dt}(S_r/m_r) = \frac{1}{m_r}\frac{dS_r}{dt}$$

$$= \frac{3}{4\pi r^3}\cdot A\mu 4\pi r^2 = \frac{3A\mu}{r} \tag{8}$$

Thus the concentration of gas in smaller droplets will increase at a faster rate than the bigger ones. In that case the concentration of pollutant will tend to be uniform in a cumulus cloud.

4·2. *Mature stage*—The start of thundershower marks the beginning of mature stage. It has been shown by Marshall (1958) and Battan (1953) that the thundershower takes place by the collision—coalescence mechanism. Radar observations on nor'westers at Calcutta during the present season reveal that the melting band is practically absent in nor'wester thundershowers. This also shows that the present thundershowers took place due to the above mechanism. If at all the Bergeron mechanism of rain formation was operating, it was having an unimportant role and might have occurred only at the fringes of the cloud, as found by Marshall (1958). We shall, therefore, consider accretion process only.

In the collision process, it is but natural to assume that bigger droplets will have a tendency to be precipitated down quickly, followed by the smaller ones. Here we have two possibilities—(*i*) If the precipitation starts immediately after the formation of cloud droplets, the concentration of salt in the resulting rain water will show gradual decrease with time because bigger droplets are concentrated and smaller ones dilute, and (*ii*) If, on the other hand, the precipitation starts after the concentration of pollutants in cloud droplets has become uniform the concentration of salt in resulting rain water will not change with time.

The falling rain drops will dissolve some more pollutants from air by washing out mechanism. It has been shown by the author (Mukherjee 1956) that by simple mechanism of washing out of salts from a rainy area where no fresh supply of polluted air is taking place, the concentration of salt decreases exponentially with progress of rain. Thus even if the rain falls just after the formation of the cloud droplets or after they have remained in air for some time, the effecting of washing out of salts from air when added up will cause the concentration of salt in rain to decrease with time.

Thundershower is maintained by the introduction of new droplets in the cloud by the updraughts. As the shower continues the air becomes cleaner and cleaner. Thus the droplets formed by the updraughts after the rain has continued for some time will get less pollutants from air to be dissolved in them. It may be assumed that under such condition the first term in the right hand side of the equation (5) will be negligible in comparison to the second. Then we will get

$$C_r = \frac{b}{r^3}. \qquad (9)$$

where, $b$ is a constant. Thus the bigger drops will be dilute and the smaller drops will be concentrated. Again, if we consider that the droplets formed by the updraught are precipitated down after a lapse of some time from their formation, smaller droplets will be more concentrated as shown by equation (8). The addition of dilute bigger droplets will cause a further decrease in salt concentration with progress of rain.

4.3. *Dissipating stage*—As long as updraught continues the bigger and dilute droplets formed by it will be precipitated down and a general trend of fall in concentration of salt (and hence conductivity) continues with progress of rain. But as soon as it stops, *i.e.*, as the dissipating stage starts, the smaller and more concentrated droplets will start precipitaing down. This will cause (*a*) gradual decrease in intensity and (*b*) gradual increase in salt concentration with progress of rain. The contribution due to washing out mechanism may be neglected at this stage. As the dissipating stage continues the air in the cloud field is gradually replaced by the environmental air which is dry and more polluted causing evaporation of and addition of pollutants in cloud droplets. The equation (5) is applicable in case of evaporation also. The pollution in environmental air towards the end of thundershower is generally low. The value of $\triangle p$ is generally high in case of evaporation. Thus in considering the evaporation of cloud droplets by environmental air we may neglect the first term on the right hand side of equation (5). Equation (9) will be applicable in that case. Equation (8) still remains applicable. All these show that as the dissipating stage continues the concentration of salt in cloud droplets and therefore in resulting rain water increases.

4.4. *Assumptions*—The following assumptions have been made in the explanation given above—

(*a*) The soluble pollutants near Calcutta are mainly gaseous. If, however, salt nuclei are regarded as mainly responsible for salinity of rain water, the explanation put forward by Roy and Srivastava (1958) may be used.

(*b*) In the beginning, the concentration of gaseous pollutant is high so that the second

term in the right hand side of equation (5) is negligible in comparison to the first.

(*c*) The air becomes very clean due to the rainfall and for droplets produced by updraught after the rain has continued for some time ,the first term becomes negligible in comparison to the second.

### 5. Some suggestions

Besides the observations and the explanation now proposed it is found that the present work leads to the following suggestions—

5·1. According to equation (5), in the industrial areas where the concentration of gaseous and water soluble impurities is high the convective cloud starts with a certain disparity of concentration of electrolytes in droplets. The bigger droplets are concentrated and smaller droplets are dilute. This again has got certain effect on further condensation of water vapour on the droplets. From equation (1) we get that the growth depends on the value of difference of ambient vapour pressure and that on the surface of this growing droplet. The higher the concentration of electrolytes the higher will be the value of $\triangle p$ under a given condition. Thus in a developing cumulus cloud, the greater the supply of condensable water vapour the quicker will be the growth of bigger droplets. In case of vigorous convection, this condition is attained. Hence, over an industrial area a vigorously growing cumulus will soon give rise to shower by collision-coalescence process without the help of any gaint salt nucleus.

5·2. The rise in conductivity with fall in intensity of rain is a peculiarity of the dissipating stage.

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