Electrical Atomization of Water Dripping from Plant Leaves

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ABSTRACT

Electrical atomization of water dripping from plant leaves has been studied. It is observed that when a high positive d.c. voltage of 8–10 kV is applied to a plant then the water dripping from its leaves tips comes off the tips as a smoke of very fine monodisperse particles. Voltages required to produce the smoke and the currents associated with it have been measured. Possible significance of this phenomenon in transferring charge from foliage to the atmosphere below thunderstorms, and its probable role in introducing charged aerosols and organic and living materials into the atmosphere are discussed.

1. Introduction

When a high positive d.c. voltage is applied to a low-conductivity liquid placed in a capillary and the flow rates are kept low, then at some particular value of voltage, water comes out of the capillary tip as a smoke of very fine monodisperse particles (Vonnegut and Neubauer, 1952; Drozin, 1955). Vonnegut and Neubauer indicated the possible significance of this phenomenon in atomizing water drops on foliage and from the crests of waves in high electrostatic fields below thunderstorms. We have carried out some experiments on water drops dripping from plants leaves and the results are reported here.

2. Experimental Set-up

Two species of plants, *Ellitaria* and *Pandanus-sp,* which have somewhat pointed leaves were used in our experiments; however, the results are applicable to other plants and trees as well. Flower pots having these plants (about 0.5 m high) were placed on a teflon sheet, and a leaf of the plant was kept wet by dropping distilled water on it through a plastic tube, its other end being connected to a water reservoir which was insulated from the ground. Flow of water could be adjusted with a cock and it was so adjusted that a drop of water fell down the tip of the leaf at an interval of a few minutes. The tip of the wet leaf was illuminated with a light source. Voltage to the plant was applied through an electrode inserted into the moist soil in the flower pot and connected to a high-voltage d.c. power supply (±50 kV). The tip of the wet leaf was kept at least 0.5 m away from any grounded object.

3. Observations

As the voltage applied to the plant is raised to a few kilovolts, any water drop suspended at the tip of the leaf falls off. At applied voltages of 8–10 kV a smoke of very fine monodisperse particles coming off the tip of the leaf is observed. Fig. 1 shows the smoke from a tip of the leaf of an *Ellitaria* plant when a voltage of 9.5 kV is applied. The smoke coming off the leaf-tip is similar to that coming out of the capillary tips. Most of the leaves of different plants we examined produced smoke in the voltage range of 8–10 kV. However, the range of voltage in which the smoke was visible from an individual leaf, generally did not exceed ~0.5 kV. Presence of water at the leaf-tip is essential for the smoke to be observed. If the dripping of water on the leaf is stopped, smoke also disappears as soon as the leaf-tip is left with no layer of water.

Similar to the observation of Vonnegut and Neubauer (1952), the smoke when illuminated with a parallel beam of light, sometimes showed higher-order Tyndal spectra indicating that the particles were uniform and of the diameter of 1 μm or so. Any change in the voltage changed the intensity of the smoke.

If a grounded electrode is brought close to the leaf-tip, the smoke could be observed at much lower voltage. For example, Fig. 2 shows smoke from the tip of a leaf of an *Ellitaria* plant when the applied voltage is only 5.0 kV and a grounded plate is placed about 2.5 cm away and perpendicular to the leaf-tip. However, smoke was observed only when the plant was at positive potential, i.e., either the positive voltage was applied to the plant or the negative voltage was applied to the electrode and the plant was grounded. It may be noted that Vonnegut and Neubauer (1952) also observed smoke coming out of the capillary tips, only when positive potentials were applied to the water inside the capillary.

We made some measurements of the current carried by the smoke from the leaf-tip to an electrode

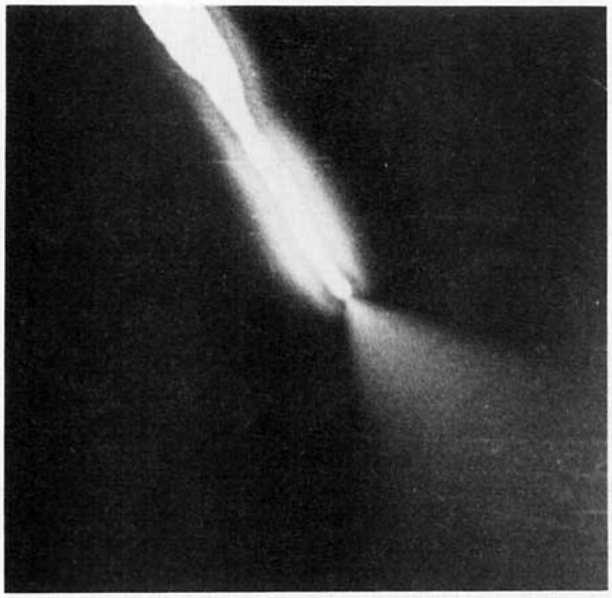

FIG. 1. Smoke of very fine water droplets coming off the tip of a wet leaf of *Ellitaria* plant when a positive d.c. voltage of 9.5 kV is applied to the plant.

placed a few centimeters below the tip and grounded through a Keithley Electrometer. When positive voltage applied to the plant is smaller than the one required to produce the smoke, the current reaching the electrode is fluctuating and in the range of 10^{-11} to 10^{-9} A. However, as the voltage is raised and the smoke appears, the current rapidly increases to 10^{-8}–10^{-7} A. The current is comparatively more steady when the smoke is well-established and thereafter, too. Polarity of the current is such as to bring positive charge to the electrode. With further increase in voltage, the smoke disappears but the current continues to increase and soon attains a value $O(10^{-6})$ A. This is presumably the corona current which sets in at potentials which are probably very close to the ones required to observe smoke.

When more than one leaf are made wet and positioned with their tips at equal distances above the electrode then the magnitude of the total current associated with the smoke is approximately equal to the number of leaves multiplied by the current from a single leaf.

Magnitudes of current flowing from the leaf-tip to the electrode were observed to be quite sensitive to the fact whether the tip of the leaf was brown (dry) or perfectly green even if the rest of the leaf was perfectly green. With no water put on the leaf, currents through green-tipped leaves were much higher than through brown-tipped ones; differences being 4 to 5 orders of magnitude at voltages higher than those required for smoke production. This may presumably be because of brown tips, being bad conductors, not going into corona even at these high voltages. However, when the leaf tips were made wet by dropping water on them, the currents flowing from brown and green tips were not much different at voltages higher than smoke producing voltages. Both green and brown tips however, produced smoke and the onset of smoke was accompanied with a rapid increase in the current. Most of the measurements reported above were made of leaves having slightly brown tips.

4. Discussion

It will be appropriate to mention here the observation of Fish (1972) who reported the generation of sub-micron sized wax particles when pine needles are exposed to high potentials. Fish suggested that these particles might produce the blue haze observed above heavily forested areas. Observation of the smoke reported here is basically different from Fish's observation in the respect that dripping of water from leaf tip is essential for the smoke to be observed in our experiments. Moreover, the potentials required to produce smoke in our experiments are comparatively much lower than those reported by Fish. Also, the smoke observed by us is visible over only a narrow range of potentials.

Negative potential gradients (earth positive) of a few kilovolts per meter are quite common at ground surface below thunderstorms. Therefore, leaves in the upper portions of a tree a few meters high are ex-

FIG. 2. Smoke of very fine water droplets coming off the tip of a wet leaf of *Ellitaria* plant when a positive d.c. voltage of 5.0 kV is applied to the plant and a grounded plate is kept 2.5 cm below the tip.

pected to be at a difference of potential of 8–10 kV or more from the surrounding atmosphere. It is quite probable therefore, that rain water dripping from such leaves under thunderstorms may be atomized and produce smoke similar to that observed in our experiments.

Potentials at which smoke has been observed from leaf tips are in the range of the critical potentials at which corona starts from the artificially raised points or trees in the atmosphere. Corona currents can, however, be one to two orders of magnitude larger than the currents associated with the smoke. However, the noticeable feature of the phenomenon is that while corona occurs under both positive and negative potential gradients, the smoke can be produced only under negative potential gradients, i.e., when the earth is positive. Incidentally, the potential gradients are mostly negative under thunderstorms. Therefore the net contribution of the smoke phenomenon will be to provide a negative charge to the earth and positive space charge to the atmosphere. Proper assessment of the magnitude of this contribution, however, requires further exploration in this direction. Another point worth mentioning is that the charges released into the atmosphere by corona are initially high-mobility small ions which may soon attach themselves to larger aerosol particles and become large ions. On the other hand, charges released by smoke phenomenon are low-mobility micron-sized water droplets which, as discussed below, may soon evaporate leaving behind charged aerosol particles.

It is worth considering as to what happens to the atomized water particles that are emitted from the leaf. Since the air under a thundercloud is usually unsaturated, it is expected that the drops produced by electrical atomization will evaporate soon after they have been released. It is quite possible therefore, that as the surface charge density increases, the droplets that have been produced as smoke, may very well become unstable and break up into even smaller particles (Doyle *et al.*, 1964).

Since the rain water dripping from plant leaves is not expected to be pure water, it is probable that when the drops evaporate, they will leave significant residues of nonvolatile solutes. Thus the electrical atomization process may be expected to lead to the introduction of electrified aerosol particles in the atmosphere. When flow rates of about 10^{-5} cm^3 s^{-1} were used, drops of diameters roughly estimated as a few tenths of a micron were produced. Thus the number of drops produced is of the order of 10^9 s^{-1}. Even if we do not consider their further disintegration into smaller drops, charged aerosol particles may be introduced into the atmosphere at this rate from a single leaf. From this flux of aerosol particles we can make a rough estimate of the amount of material that might be introduced into the atmosphere.

An effective separation of about 10 m is generally taken between trees (Chalmers, 1967) for calculating point discharge currents below thunderstorms. This gives 10^4 trees per km^2. Therefore the number of trees below a thunderstorm covering an average area of about 10 km^2 will be 10^5. As a rough estimate, if we assume that the number of leaves producing smoke at any time from a single tree is of the order of 100, then the total number of leaves producing smoke below a thunderstorm, covering an area of ~ 10 km^2, will be $O(10^7)$. All over the globe, about 2000 thunderstorms are considered to be active at any time, so that the total number of leaves producing smoke will be $O(10^{10})$. This estimate may not change much when one considers that part of these thunderstorms are active over ocean. Therefore, total number of aerosol particles introduced into the atmosphere may be 10^{26} per year. Now, since the total amount of material generally observed in rain water is of the order of 10^{-2} g kg^{-1}, a water drop of the diameter of a few tenths of a micron, may evaporate to give a solid particle of 10^{-20} g (assuming an average density of the materials to be a few g cm^{-3}). It follows therefore that the total amount of material introduced into the atmosphere by this process, may be of the order of 10^6 g per year.

It is conceivable that the electrical atomization process discussed here may not only introduce inorganic materials into the atmosphere, but that organic materials from the plant and even living material in the form of bacteria and viruses may be introduced and levitated into the atmosphere beneath thunderclouds, as in the Blanchard phenomenon (Blanchard and Syzdek, 1974) produced by bursting bubbles.

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REFERENCES

Blanchard, D. C., and L. D. Syzdek, 1974: Importance of bubble scavenging in the water-to-air transfer of organic material and bacteria. *J. Rech. Atmos.*, **8**, 529–540.

Chalmers, J. A., 1967: *Atmospheric Electricity.* Pergamon Press, 260–261.

Doyle, A., D. R. Moffett and B. Vonnegut, 1964: Behaviour of evaporating electrically charged droplets. *J. Colloid Sci.*, **19**, 136–43.

Drozin, V. G., 1955: The electrical dispersion of liquids as aerosols. *J. Colloid Sci.*, **10**, 158–164.

Fish, B. R., 1972: Electrical generation of natural aerosols from vegetation. *Science*, **175**, 1239–1240.

Vonnegut, B., and R. L. Neubauer, 1952: Production of monodisperse liquid particles by electrical atomization. *J. Colloid Sci.*, **7**, 616–622.