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The electrification of snowstorms and sandstorms

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SUMMARY

An analysis is made of available observations on the electrical properties of natural and artificial snowstorms. An explanation for this electrification is given in terms of a theory of charge transfer associated with temperature gradients in ice, which has been shown earlier to provide a tenable theory of thunderstorm electrification. Further analysis shows that sandstorms exhibit similar electrical effects to those of snowstorms, and it is suggested that the temperature gradient effect may provide an explanation for sandstorm electrification.

1. INTRODUCTION

The electrical effects associated with blizzards were first studied in detail by Simpson (1921) who found that, in general, the blowing of snow was accompanied by a large increase in the normal positive potential gradient of the atmosphere close to the ground. Observations made subsequently by other workers have confirmed those of Simpson. Laboratory experiments in which the conditions obtaining in a snowstorm were simulated, and in which snow was disrupted by an air jet or allowed to make violent impact with a snow block, showed that electrification was produced; charge was measured on the air, on the blown snow particles, and on the snow block. No explanation was offered for the cause of the measured electrification.

A similar state of affairs exists in the case of the electrification of sandstorms, although this field is not so well documented. Observations on natural sandstorms show that strong potential gradients are built up in the air close to the ground during the time that sand is being blown. Again, laboratory experiments on the blowing of sand indicate that considerable charging can result and that the air – or tiny sand particles suspended in the air – acquires charge of one sign, charge of the opposite sign residing on the blown sand particles. As in the case of snowstorms, no explanation has been given for the cause of the electrification.

The similarities between the electrical properties of these two phenomena, snowstorms and sandstorms, are so striking that it is tempting to ascribe to them a common mechanism of electrification. The object of the present paper is to analyse the available evidence and to demonstrate that there is a strong possibility that temperature gradients were responsible for the observed electrification in both cases.

In the case of snow, a mechanism by which electric charge transfer can result from temperature gradients has been described by Latham and Mason (1961a). The mechanism depends essentially on the following facts : (1) the concentrations of H^+ and OH^- ions in ice rise quite rapidly with increasing temperature, (2) the mobility of the H^+ ion is much greater than that of the OH^- ion. Thus the establishment of a temperature gradient in a specimen of ice will be accompanied by a concentration gradient of ions of both signs. The more rapid initial diffusion of the H^+ ions down the concentration (temperature) gradient will lead to a separation of charge with a net excess of positive charge in the colder part of the ice. Latham and Mason showed that when a steady temperature difference ΔT is maintained across a uniform ice specimen a potential difference of numerically about 2 ΔT millivolts will be developed across it, the colder end becoming positively charged and the warmer end negatively charged. By similar reasoning, when two pieces of ice at initially different temperatures are brought into contact and separated, the warmer acquires a negative charge and the colder an equal positive charge of maximum value $3 \times 10^{-3}\ \Delta T$ e.s.u. cm^{-2} after a contact time of about 0·01 sec. These predictions were confirmed by a series of experiments on highly purified ice. Latham and Mason (1961b) proceeded to show how this mechanism may be operative in the generation of electricity in thunderstorms. They concluded from experiments in which thunderstorm conditions were simulated that the electrification of growing rime deposits, which was shown to be produced by temperature gradients in the ice shells surrounding droplets of freezing supercooled water, satisfies all the conditions necessary for a satisfactory explanation of thunderstorm electrification.

However, as described by Henry (1952), charge transfer associated with temperature gradients is not restricted to ice. Henry pointed out that, in general, for any substance whose concentration of free charge carriers is a function of temperature, charge transfer should occur if a temperature gradient is applied to a specimen of the substance or if two pieces of the same substance, of different temperature, are brought into contact. He demonstrated this effect for various insulators.

A description now follows of the observations that have been made on the electrification of snow and of sand, in both natural storms and in the laboratory, and an attempt is then made to explain these observations in terms of charge transfer accompanying temperature gradients established in ice and in sand respectively.

2. The electrification of snowstorms

Simpson (1921), on an expedition to the Antarctic, made several thousand observations of the potential gradient of the atmosphere at a point near the surface of the earth when snow was being blown. Almost without exception he found that a large increase in the normal positive gradient was produced, indicating that the air contained positive charge, a compensating negative charge residing partly on the heavier snowflakes blown at a lower level and partly on the earth's surface; he also observed that the snowstorms produced pronounced interference with radio-communication. Pearce and Currie (1949) also observed a huge increase in the value of the positive space-charge density in a snowstorm. Simpson proposed that collisions between snowflakes caused them to acquire a negative charge, leaving a compensating positive charge on the air as ions or as tiny fragments of ice broken off the large snowflakes in the collisions. He argued that owing to the irregularities of the air motion the charged air near the ground mixes with the air above and in a short time the whole of the air above the ground, probably to several hundred feet, becomes quite highly charged with positive electricity. Between the positively charged air and the ground an intense electric field may be set up. The direction of the field was the same as that of the normal field of the atmosphere and therefore it can be concluded that the effect of surface drift is to produce a high positive potential gradient. The potential gradient of the atmosphere was found to increase when the velocity of the surface wind increased.

Simpson showed that on all occasions in a snowstorm positive charge is situated in the air at a greater elevation than negative charge. This is consistent with the temperature-gradient theory of Latham and Mason, as can be seen from the following argument. The extremities of snowflakes will be colder than the interior because of extra evaporation, and will therefore become positively charged, the equivalent negative charge remaining in the interior. On collision with other snowflakes or the ground, or on exposure to violent winds, the extremities will break off and will produce tiny positively charged splinters which are carried upwards by ascending air currents, leaving a negative charge on the heavier snowflakes below. Thus a field of the observed polarity will be produced, increasing with wind velocity because of the greater evaporation and amount of splintering.

The fact that large numbers of ice fragments can be produced by the collision of snowflakes with an obstacle at high velocity has been established by Schaefer (1947), who found that at velocities similar to those occurring in snowstorms stellar ice-crystals could shatter to produce 500 pieces, while hexagonal plates and columns would produce about 30 fragments.

Pearce and Currie found that, in a snowstorm, flakes that were blown against the snow-covered roof of a hut before entering a collector were more negatively charged than those that fell straight into the collector from the cloud, i.e., the sliding of snowflakes over a snow surface causes the flakes to acquire a negative charge. This conclusion is reinforced by their observation that when snow drifts the blown flakes are always negatively charged. These observations are consistent with the temperature gradient theory, as a snowflake sliding over the snow on the roof of the shed or over the surface snow during drifting will become heated by friction to a higher temperature than the snow with which it comes into contact, because the area of contact is very much smaller for the flake. Contact between the snowflake and the colder roof or surface snow will cause the flake to acquire a negative charge, as was observed.

This ' asymmetric rubbing ' mechanism of charge transfer was suggested by Henry (1952). It was observed for large ice specimens by Reynolds, Brook and Gourley (1957) and Latham (1963a), and for small ice crystals by Latham and Mason (1961b) who found that when a stream of ice crystals was allowed to impinge against and rebound from an ice-coated copper sphere it became positively charged when apparently at the same temperature as the impacting crystals; it was demonstrated that the temperature differences responsible for charge transfer were produced on contact by asymmetric rubbing. This effect is identical in sign to that found for snow by Pearce and Currie, and both are explicable in terms of the temperature gradient theory.

Some laboratory studies have been made of the electrification produced by the blowing or sliding of snow. Pearce and Currie eroded a snow-block by means of an air-blast of the same temperature as the snow. They found that whereas the visible particles swept off the block were negatively charged, the block attained a positive charge as did the air (or, more probably, extremely fine ice particles suspended in the air). They observed that charging was associated with fracture of snow. When they allowed snow to blow against a snow block they found that the blown snow became negatively charged and that the air acquired a positive charge. Small experiments by Stager (1925a, b), Boning (1927) and Chapman (1952) yielded inconclusive and contradictory results for the electrification produced by ice-ice impact and snow fracture; the erratic results obtained can probably be attributed to lack of adequate control over the parameters important in producing charge transfer. However, consistency was achieved by Chalmers (1952), who rubbed two handfuls of snow together and allowed the fragments so produced to fall into a collector connected to an electrometer. On every occasion a negative charge was recorded. Norinder and Siksna (1953) poured snow through a funnel coated with ice and then collected it in a can connected to an electrometer; they found that it acquired a negative charge. They also observed that when snow was blown against an insulated ice-coated target the rebounding snowflakes carried a negative charge while the air and the target acquired a positive charge. All these observations are identical with those described above for natural storms, and can therefore be explained in terms of the temperature gradient theory; asymmetric rubbing gives a negative charge to the blown or sliding snowflakes and fragmentation gives a positive charge to the air.

There is considerable experimental evidence (Findeisen (1940, 1943); Lange (1940); Kramer (1948); Pearce and Currie (1949); Kumm (1951)) to show that when air currents of a few cm/sec velocity are allowed to flow past a deposit of frost grown by sublimation, small splinters are broken off the fragile dendritic crystals and carry away charges of predominantly one sign, leaving those of opposite sign on the parent crystal; such a fragmentation process will occur in snowstorms when snowflakes composed of delicately branched crystals collide, or splinters may be torn off by frictional drag with the air. This work was analysed by Latham (1962), who showed that the observations were in qualitative agreement with the temperature gradient theory, and then (1963b) proceeded to investigate in detail the electrification associated with frost splintering. Air currents were allowed to flow past a frost deposit whose temperature could be made higher or lower than that of the air stream. It was found that the deposit became negatively charged if it were warmer than the air stream and positively charged if it were colder. The ejected splinters were found to carry a charge of opposite sign to that on the deposit. Latham showed that these results were explicable qualitatively and quantitatively in terms of the temperature gradient theory.

The above discussion shows that all well-authenticated observations on the electrification of blowing or sliding snow, whether in natural storms or in the laboratory, can be interpreted qualitatively in terms of the theory of Latham and Mason involving preferential migration of protons down temperature gradients in ice.

3. The electrification of sandstorms

Although it has been established that strong electric fields can be built up in sandstorms (Shaw (1927); Gill (1948)) resulting in the production of sparks and interference with radio-communication, very few measurements have been made on the electrical properties of either natural or artificial sandstorms.

Freier (1960) recorded the electric field of a large dust-devil in the Sahara Desert; his records indicated that its polarity was negative; i.e. negative charge is situated above positive charge. Electrical measurements on sandstorms by Hatakeyama and Kubo (1947) were extremely erratic and difficult to interpret, but suggested that there may be a seasonal variation in the sign of the electric field. Rudge (1914) disrupted sand by means of an air jet and found that large particles acquired a positive charge and the air (or probably very small particles of sand suspended in the air) a negative charge. The sign of the charging was reversed if the sand was poured through a funnel instead of being blown. Shaw (1929) blew sand at room temperature through a sandpaper sheath and found that the sandpaper became positively charged and the blown sand negatively charged. The charging was of the same sign but greater in magnitude when the temperature of the air jet was increased to 58°C. Gill (1948) poured sand through a metal funnel and found that the smaller sand particles acquired a positive charge and the larger ones a negative charge. Kunkel (1950), in experiments in which great care was taken to eliminate impurities, produced a puff of sand and measured the charge carried by individual particles. He found that although most particles were charged the electrification was symmetrical, i.e., for each size range the total charge carried by the negatively charged sand particles was equal to the total charge on the positively charged particles. Peterson (1949) poured sand through a silica funnel and found that the sand acquired a negative charge. Many workers (e.g., Debeau (1944), Wagner (1956)) have observed that contact between sand and a metal can produce electrification. Gill and Alfrey (1949) poured sand down a metal slide in an electric field and found that the sign of the field influenced the sign of the resultant charge on the sand; when the electric field was zero the sand was negatively charged.

There are therefore seen to be marked similarities in the electrical properties of snow and sand. In natural snowstorms and sandstorms strong electric fields are built up which are associated with the disruption of a snow or sand surface by strong winds. In the laboratory experiments the pouring and blowing of both snow and sand produces separation of electric charge, the magnitude of which is influenced by temperature and impurities in the snow or sand.

However, as distinct from the case of snow, it can be seen from the work on sand described above that the results are contradictory; in addition, no quantitative measurements of any consequence have been made and, in general, no precautions were taken to eliminate the possibility that the measured charge transfer was due to impurities. Nevertheless, if consideration is given only to those laboratory experiments in which no conditions prevailed except those which would be present in a sandstorm, i.e., those experiments in which electrification was definitely produced by sand-sand contact, then it is possible to see a definite pattern of charge transfer. The only experiments to satisfy these requirements are those of Rudge on blowing sand, of Shaw, of Peterson, and of Kunkel. In all these experiments, (except those of Kunkel on extremely pure sand), it was found that when sand made contact with sand, the large sand particles acquired a positive charge and the small ones a negative charge. However, it is highly probable that in these experiments asymmetric rubbing would occur between the large and the small sand particles, and because of their smaller area of contact the small particles would become hotter than the large ones. Therefore, by analogy with the theory of charge transfer associated with temperature gradients in ice, if the charge carriers for sand are free ions whose concentration increases with increasing temperature and whose positive ions are more mobile than the negative ones, contact between the smaller (warmer) particles and the larger (cooler) ones should produce a separation of charge such that the smaller particles become negatively charged and the larger ones positively charged. This is in agreement with the laboratory measurements of Rudge, Shaw and Peterson. It also accords with the observation of Freier that the dust-devil has a negative polarity, because gravitational separation of the heavier (positive) sand particles and the lighter (negative) ones would cause the dust-devil to have negative charge at its top and positive charge lower down, as observed. The possibility suggested by Loeb (1958) that the charge carriers in these experiments were impurity ions is reinforced by Kunkel's observation of solely symmetrical charging when the sand was very pure.

It is seen, therefore, that the possibility that the electrification of sandstorms is produced by asymmetric rubbing and the consequent preferential migration of ions of one sign from a hotter body to a colder one, as described by Henry and investigated for ice by Latham and Mason, is consistent with all the available evidence. However, this evidence is scanty. No quantitative measurements have been made. The charge carriers involved in the electrification have not been identified. In addition, sand is known to exhibit pyro-electric and piezo-electric effects, which may have been operative in the experiments described above.

Conclusions

The electrical effects occurring in natural snowstorms and in laboratory experiments on the blowing and sliding of snow are in qualitative agreement with the temperature gradient theory of Latham and Mason. The electrical effects associated with natural and artificial sandstorms bear a marked resemblance to the snowstorm electrification phenomena and are explicable in terms of a similar temperature gradient effect; however, in this case the possibility exists that other effects may have been responsible for the observed charge transfer.

It appears that an intensive laboratory investigation of the electrification produced by the blowing of sand and snow is required, in which firm control is exercised over the temperatures of the particles and of the air, the size and shape of the blown particles and their degree of purity. It should be possible to determine from this work, whether the temperature gradient mechanism affords a quantitative explanation for the electrical properties of snowstorms, and whether it is of major importance in sandstorm electrification.

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