LII. On the electrification associated with dust-clouds

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This equation can of course only be true so long as the ions behave as perfect gases. The increase in osmotic pressure of an ion for a change in potential of 0.1 volt is about 80 fold. So that if the solution were decinormal potassium chloride it would scarcely be legitimate to use the formula for a greater value of V than 0.1 volt. Unfortunately, the change in surface tension for an alteration in the applied electromotive force of 0.1 volt when the surface tension is at its maximum is so small that it cannot be accurately measured. I estimate from S. W. J. Smith's* electrocapillary curves and Quincke's value for the surface tension of mercury in contact with hydrochloric acid (assuming that the surface tension of mercury in contact with hydrochloric acid is the same as that of mercury in contact with a solution of potassium chloride), that the fall in surface tension when V is 0.1 volt lies between 3.5 and 4 c.g.s. units when the mercury is in contact with $\frac{N}{10}$ KCl. The fall in surface tension

calculated from the above formula for the same change in the applied electromotive force is 4.8 c.g.s. units. It is therefore very probable that the observed change in surface tension can, as Helmholtz postulated, be largely accounted for by the electric charges in the double layer.

It is obvious that what is most needed to elucidate the mechanism of the capillary electrometer is a very thorough examination of the electrocapillary curve in the region of maximum capillarity, preferably with solutions which give no electromotive force in contact with mercury, such as those used by Palmaer† to investigate the electromotive force of the calomel electrode.

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LII. *On the Electrification associated with Dust-Clouds.* By W. A. DOUGLAS RUDGE, *Professor of Physics, University College, Bloemfontein* ‡.

[Plates VI. & VII.]

THE author has shown § that a considerable amount of electrification is imparted to the atmosphere by clouds of dust raised by the wind, and it seemed of interest to investigate the electrification developed by raising clouds

* *Zeit. f. Phys. Ch.* xxxii. p. 467 (1900).

† *Zeit. Elektrochemie*, ix. p. 754 (1903).

‡ Communicated by the Author.

§ *Phil. Mag.* June 1912; *Proc. Roy. Soc. South Africa*, 1912; *South African Journ. Sci.* 1912.

of dust composed of various materials, by artificial means. As has been shown *, the electrification developed during dust storms in South Africa is invariably negative, neutralizing and reversing the positive charge usually present in the air. In England, in places where the matter was tested, the clouds of dust raised by motor-cars had the effect of *increasing the positive charge*. In South Africa the dust is usually of a siliceous character, whether it comes from the sea-shore, inland wastes, cultivated soils, or the mine-heaps in the neighbourhood of Johannesburg. In England "road dust" is usually calcareous. It is quite easy to show the production of a charge of electricity by raising a cloud of dust. If a small quantity of flour is placed upon the plate of an electroscope and then suddenly blown away, the electroscope will indicate a charge whose magnitude will depend to some extent on the fineness of the flour. The experiment can be performed in a room, but the effect is very much greater if it is done out in the open air. By raising a cloud of flour-dust in any way and catching the particles in a hollow insulated vessel, it is always possible to show the presence of a charge of electricity.

The apparatus used for systematic investigation consisted of a small cylinder of fine wire-gauze 10 cm. in length and 2 cm. in diameter, which was attached to a hollow brass cylinder of the same diameter. A nozzle projected a short

Fig. 1.

distance into the brass cylinder, and if some powder was arranged in front of the nozzle a sharp puff of air would blow it into a cloud, and the particles would be carried through the meshes of the wire gauze and give up a portion

* Phil. Mag. June 1912; Proc. Roy. Soc. South Africa, 1912; South African Journ. Sci. 1912.

of their charges to it (fig. 1). The cylinder was insulated by an ebonite rod and connected to a sensitive gold-leaf electroscope of the pattern designed by C. T. R. Wilson. An ordinary instrument suffices in most cases, as the charges developed are quite strong. The air current was usually obtained from a Fletcher bellows, but a sharp puff from the mouth was quite efficacious. When fine sand or dry earth was used a strong positive charge was indicated, as would have been expected from what was shown in a previous paper * ; but on using other material, the charge was *positive* or *negative*, according to the nature of the material.

Almost the only references to the electrification of dusts are those relating to the production of Lichtenberg's figures, by shaking a mixture of red lead and sulphur in a muslin bag, and allowing the powders to fall upon an irregularly electrified plate composed of some non-conducting material. A separation of the red lead and sulphur particles is effected because of the opposite charges acquired by these materials, the sulphur particles being stated to be negatively electrified, whilst those of the red lead are positive. Now, powdered sulphur when blown into a cloud in the apparatus acquires a POSITIVE charge, and red lead a NEGATIVE one. This fact seemed sufficient to warrant an investigation into the kind of electrification accompanying the raising of clouds of dust from different materials.

A great many experiments were made with those materials usually found in the chemical laboratory, and very shortly it was seen that the electrification developed appeared to follow some general laws ; and although there are many apparent exceptions—probably due to the use of materials whose purity is doubtful—the laws given below are fairly well established by the experiments. The materials used were taken from the stock-bottles in the laboratory and no attempt was made to purify them. The experiments were conducted out of doors, and the results are tabulated below.

Law I. Non-metallic elements give positively charged clouds when the finely divided material is blown into a cloud by a current of air.

Of course, only solid elements can be dealt with in this manner.

* Phil. Mag. June 1912.

TABLE I.

Element.	Charge.	Remarks.
Carbon	+	Magnitude of charge varied with the kind of carbon.
Sulphur	+	Very strong charge.
Phosphorus	+	Amorphous and carefully dried.
Silicon	+	Strong * charge.
Boron	+	" "
Selenium	+	" "
Tellurium	+	" "
Iodine	+	" "
Arsenic	+	Fairly strong.

* By strong, one means that a few centigrammes of the substance would produce sufficient electricity to send the gold-leaf out to a right angle.

Particular note should be taken that the so-called *metallic* arsenic is included in the above list. Carbon occurs in several modifications, and of these wood and sugar charcoal and diamond dust were strongly positive, graphite not very definite and sometimes strongly negative, whilst "animal" charcoal, a mixture of various substances, gave practically no electrification. Sulphur in all its modifications was always strongly positive. Amorphous phosphorus was, of course, the only kind which could be used.

Law II. *Metallic elements give negatively charged clouds when the finely divided material is blown into a cloud by a current of air.*

As a positive charge seemed to be associated with a non-metallic dust-cloud, it seemed likely that a metallic dust should give a negatively charged cloud, and this was borne out by the experiments; but, as is seen from Table II., some important exceptions occur.

The list of metals is far from being complete, but it is very remarkable that those which are so definitely "metallic" in their character should acquire a negative charge; whilst tungsten and vanadium, which form strongly acid oxides, *i. e.* approximating to the nature of a non-metal, should, under the same circumstances, give positive charges. Uranium and titanium should probably be included in the same category, but the charges obtained were indefinite, and only a small quantity of the material was available. One would expect zirconium to behave similarly to calcium or aluminium, but the material was probably impure. Only those metals could be used which were obtainable in a finely

divided state. In the case of iron the results were the same, whether filings or reduced iron was used.

TABLE II.

Metal.	Charge.	Remarks.
Aluminium	—	Strong.
Antimony	—	"
Bismuth.....	—	"
Cadmium	—	Weak.
Calcium.....	—	Very strong.
Cobalt	—	Strong.
Copper	—	Weak.
Iron	—	Strong.
Lead	—	"
Magnesium	—	"
Nickel	—	Variable.
Silver	—	Weak.
Tin.....	—	"
Titanium	?	Variable.
Tungsten	+	Strong.
Uranium	?	Variable.
Vanadium.....	+	Very strong.
Zinc	—	"
Zirconium.....	+	Weak.
Platinized Asbestos* ...	—	Strong.

* Compare Asbestos, Table IX.

The charges obtained on the clouds of dusts of metals and non-metals are thus of a character opposite to those associated with the ions of the elements when in solution, and from this the inference was drawn that clouds of dusts from solid acids should also be positively charged, and here again the inference was strikingly substantiated, only one exception being noted. The acids used are mainly organic ones, as only solid acids could be used.

TABLE III.

Acid.	Charge.	Acid.	Charge.
Anthranilic	—	Malonic	+
Benzoic	+	Molybdic	+
Boric	+	Molib	+
Citric	+	Oxalic.....	+
Chromic	+	Phthalic.....	+
Ferrocyanic	+	Salicylic	+
Galic	+	Sulphanilic	+
Hippuric	+	Tartaric.....	+
Metastannic	+		

The anthranilic acid was not tested as to its identity, as the quantity was very small.

A systematic investigation of the oxides of metals and non-metals was made, the results being shown in Table IV. Oxides may roughly be divided into "acidic" and "basic" groups, the former being oxides of non-metals and the latter those of metals, but of course the rule is not rigidly followed, as many metals give acid oxides. We should thus expect to find that some oxides should give positive clouds, and others negative ones.

TABLE IV.

Oxide.	Charge.	Oxide.	Charge.
Aluminium Al_2O_3	—	Magnesium MgO	—
Antimony Sb_2O_3	—	Manganese MnO	+
" Sb_2O_5	+	" MnO_2	+
Arsenic As_2O_3	+	Molybdenum MoO_3	+
" As_2O_5	+	Mercury Hg_2O	—
Barium BaO	—	" HgO	—
" BaO_2	—	Nickel NiO	—
Bismuth Bi_2O_3	—	Phosphoric P_2O_5	+
Cerium Ce_2O_3	—	Tin SnO_2	+
Copper Cu_2O	—	Titanium TiO	+
" CuO	—	Tungsten WO_3	+
Chromium Cr_2O_3	+	" W_2O_5	+
Iodine I_2O_5	+	Uranium UO_3	+
Iron FeO	—	" UO_2	+
" Fe_2O_3	—	Vanadium V_2O_5	+
Lead PbO	—	Zinc ZnO	—
" PbO_2	—	" ZnO_2	—
" Pb_3O	—	Zirconium ZrO	—

Manganous oxide MnO and chromic oxide might be expected to give negative charges as they are decidedly basic. Molybdenum, tungsten, and uranium form strongly acid oxides. One oxide of antimony is basic and the other acidic. The oxides of arsenic, phosphorus, and iodine are, of course, very strongly acidic. From this table and the preceding one another law may be deduced.

Law III. *Solid acids and acid-forming oxides give positively charged clouds, and basic oxides negatively charged ones.*

Assuming the truth of law III, it was of interest to speculate as to what should be the nature of the charge obtained on the cloud formed by raising a dust from a finely powdered salt. Would the character of the base or the acid

predominate? With this idea in view, groups of salts were studied in which the acid was "strong" or "weak" relatively to the base, and Table V. shows the results obtained with the carbonates. Carbonic acid may be regarded as a "weak" acid, so that the electrification due to the base might be expected to be dominant.

TABLE V.

Carbonate.	Charge.	Carbonate.	Charge.
Ammonium	- ?	Iron	+
Barium	-	Lead	-
Beryllium	-	Magnesium	-
Bismuth	-	Manganese	-
Cadmium	+	Lithium	-
Calcium	-	Potassium	-
Cobalt	-	Sodium	-
Chromium	+	Strontium	-
Copper	-	Zinc	-

There are three exceptions occurring in this table, which may have been due to contamination, as it seems anomalous that chromium and iron carbonates should differ from the carbonates of cobalt, manganese, and nickel.

Nitric and hydrochloric are "strong" acids, and here it might be expected that the electrification produced would be positive, if the reasoning applied to the carbonates was correct, and this is substantiated by Table VI. Even aniline chloride obeys the rule.

TABLE VI.

Salt.	Charge.	Salt.	Charge.
Ammonium chloride ...	+	Potassium chloride	+
Barium " ...	+	Sodium " ...	+
Calcium " ...	+	Strontium " ...	+
Copper " ...	+	Barium nitrate	+
Lead " ...	+	Bismuth " ...	+
Mercurous " ...	+	Lead " ...	+
Mercuric " ...	+	Potassium " ...	+
Aniline " ...	+		

Sulphides gave very strongly charged clouds, which were generally positive.

TABLE VII.

Sulphide.	Charge.	Sulphide.	Charge.
Antimony, Red	+	Mercuric Black	+
Antimony, Black	+	Mercuric Red	+
Barium	+	Potassium	0
Calcium	+	Tin	+
Copper	+	Zinc	-
Iron	+		

Reasoning by analogy with the carbonates, we might have expected sulphides to give negative charges, because hydro-sulphuric is a weak acid in solution, but sulphides are very stable compounds, so that perhaps in combination the acid is strong.

Sulphates show considerable variation, but an isomorphous group produced the same charge. Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, gives a positive charge, but after the water of crystallization was driven off by heating, the anhydrous sulphate gave a negatively charged cloud.

The alkaloids are a well-known group of basic bodies, and all give strong charges when blown into clouds. With these were studied some allied bodies, and the results obtained are shown in Table VIII.

TABLE VIII.

Substance.	Charge.	Substance.	Charge.
Aconitine	-	Morphine chloride	+
Atropine	-	Quinine	-
Brucine	-	Quinine sulphate	-
Caffeine	+	Strychnine	-
Cantharidine	-	Salicin	+
Cinchonine	-	Tannin	+
Cocaine	-	Theine	+
Codeine	-	Vanillin	+
Morphine	-	Guaiacum	+

It is very remarkable that all those alkaloids which are of more or less similar constitution should give negative charges, whilst morphine chloride behaves as other chlorides and gives a positive charge. Theine and caffeine are undoubtedly the same substance, and although classed with the alkaloids

are really derivatives of uric acid and should be called ureides; salicin, tannin, vanillin, and guaiacum are probably glucosides, and all give similar charges to each other but different from those of the alkaloids.

In Table IX. there is given a number of miscellaneous substances which do not admit of convenient classification, but those materials to which an acidic character is usually attributed do in general give rise to positive electrification.

TABLE IX.

Substance.	Charge.	Substance.	Charge.
Calcium fluoride	—	Fine soil	+
Zinc chromate	+	Asbestos	+
Precipitated silica	+	Lycopodium	—
Dextrose	—	Methyl orange	—
Dextrine	—	Calcium acetate	—
Starch	+	Potassium iodide	+
Flour	—	" bromide	+
Lead tartarate	+	" permanganate	—
Tartar emetic	+	" chromate	—
Sodium aluminate	—	" bichromate	+
" salicylate	—	" fluosilicate	+
" bisulphite	—	" hydrate	—
Ammon. bichromate	+	" ferrocyanide	+
Copper cyanide	+	" phosphate	+
Lead chromate	—	" sulphite	—
Resorcin	+	" bitartarate	—
Pyrogallol	—	Urea	+
Carborundum	+	Urea nitrate	+
Tricalcic phosphate	—	Toluidine	—
Monocalcic phosphate	+	Naphthylamine	—
Sand	+	Diphenylamine	—

In this table it may be noted that neutral potassium chromate acquires a negative charge, but the acid bichromate acquires a positive. The same thing is seen with the neutral tricalcic phosphate and the acid monocalcic phosphate. Carborundum is a compound of two non-metallic elements, and should be expected to give a positive charge. Emery-powder is oxide of aluminium, and should behave as a basic oxide and thus give a negative charge. The alcohol pyrogallol, commonly known as pyrogallie "acid," is not an exception to the rule that acids should give positive charges. It is rather remarkable that starch should give a positive charge, and flour a negative one; urea is only very slightly charged, but urea nitrate yields a strong charge.

In all cases it is to be presumed that the air would acquire a charge opposite to that upon the dust, and this was first

shown to be true in the case of the iron dust-cloud. As indicated in Table II., iron acquires a negative charge, and the air should consequently be positive. In order to show this, the wire-gauze cylinder was placed between the poles of a strong electromagnet, and an insulated brass tube made to surround the end portion. A cloud of iron dust was raised in the usual manner, but most of the iron particles were retained by the magnet, and the current of air impinging upon the outer tube gave it a distinct positive charge which could be detected by removing it from the neighbourhood of the inner cylinder.

In order to be certain that the charges were actually attached to the dusts, and to the air, the method of conducting the experiments was altered. It might be considered probable that the charges shown by the metal cylinder were due to the friction of the particles upon the insulated wire gauze, but this is not the case, for if so, the charge upon the cylinders would be opposite to that upon the dust.

A second insulated wire gauze cylinder was arranged around the first (fig. 2), and on raising a cloud in the inner cylinder the dust was carried through the meshes of the gauze,

Fig. 2.

and reached the outer cylinder. *The charge indicated by both cylinders was the same.* This was not due to an induction effect, for on removing the inner cylinder the charge persisted upon the outer one. A third cylinder surrounding the second one also acquired a charge similar to that on the innermost one, so that it seems to be quite conclusive that the charge observed is actually attached to the dust particles.

The air is also carried through the cylinders with the dust, so that the charge acquired by the outer cylinder will be the sum of the charges given up by the dust and air, and these charges would of course be opposite in sign. It is possible,

however, to stop most of the dust and to deal mainly with the charge carried by the air.

A small cylinder was constructed of several layers of the finest wire gauze obtainable, and this was covered over with several layers of "chiffon," so that only the finest particles of dust could pass, but the air could do so without much hindrance. Using this cylinder, it was found possible to stop most of the dust, so that the charge acquired by the outer cylinder was mainly that due to the air. Some of the dust did get through, but probably most of the charge it possessed was removed by keeping the inner cylinder "earthed." Table X. gives the results obtained in some typical cases. The inner cylinder was insulated and earthed alternately. When insulated, the charge indicated by the outer cylinder was that due to the dust particles which succeeded in getting through, and also to the inductive effect of the inner cylinder, which had caught most of the charge upon the dust. On earthing the inner cylinder, the charge upon the dust would be removed, but sufficient would be carried by the air to give a definite charge to the outer cylinder.

TABLE X.

Substance.	Inner cylinder.	Charge upon outer cylinder.
Flour	Insulated.	—
	Earthed.	+
Sulphur	Insulated.	+
	Earthed.	—
Fine sand	Insulated.	+
	Earthed.	—
Litharge	Insulated.	—
	Earthed.	+
Boracic acid	Insulated.	+
	Earthed.	—

These examples show very conclusively that charges of opposite sign are carried by dust and by air.

Another form of apparatus was also devised, by which the dust particles could be separated from the air by allowing them to settle upon an insulated plate and then determining the

nature of the charge acquired by the plate, and also the charge upon the air could be indicated (Pl. VI. fig. 3).

A box measuring $40 \times 30 \times 30$ cm. having a well fitting door was taken. Through the top a thick plug of ebonite was passed, and through this plug a wire was joined to a plate of wire gauze. To the door of the box an insulated plate was attached, so that on opening the door a connexion could be established between the plate and an electroscope, and any charge it possessed indicated. A hole at the bottom allowed of a blast of air being introduced, and another at the top allowed the air and dust to escape (Pl. VI. fig. 3).

Some flour was placed on the bottom of the box and both electrodes earthed. A blast of air was sent in from the bellows, and after a short time the earth connexion was broken, and the top of the box tapped so as to shake off as much flour as possible from the upper electrode. On putting the electroscope in communication with this electrode, a POSITIVE charge was seen to be present. On opening the box and testing the lower plate upon which some of the flour particles had settled, a NEGATIVE charge was shown to be present. The charges were not as strong as those obtained in the open air, but they were quite sufficiently strong to admit of identification. On repeating the experiment with sulphur, the upper electrode became POSITIVE, and the lower one NEGATIVE. The charge upon the upper electrode was always more marked than that on the lower one, and the small effect in the latter case appeared to be due to (1) the particles of dust giving up their charge to the walls of the box, and (2) the comparative fewness of the particles reaching the plate.

"Lichtenberg" figures may very readily be obtained from the dust clouds formed in the box used for the last experiment; and a very marked difference is seen when the charges upon the plate are different.

A cleaned ebonite plate was touched for an instant with the knob of a charged leyden-jar. A cloud of dust was raised in the box, and as quickly as possible the charged plate was put inside. The particles of dust were attracted to the charged surface, and a well-defined "Lichtenberg" figure obtained. If flour was used, the figure was strongly developed when a positive charge had been "splashed" upon the plate; and if sulphur, then the same thing was seen if the charge was negative. Figures, however, could be obtained with both charges, but were of a different character. No doubt the electrified air moving with the dust would effect some slight modification. The photographs show some

of the results obtained by this mode of experimenting (Pl. VII. figs. 5, 6, 7, 8, 9, 10).

No. 5 is formed by starch dust, 6 from sulphur, 7 from boracic acid, 8 from aluminium, 9 that due to merely sifting sulphur upon the charged plate. Here the particles which were uncharged, simply lie as they fall, and are not directed along definite lines as is the case with the particles from the dust clouds. 10 is due to sulphur sprayed, and consequently charged, upon a positively charged surface.

The easiest way to obtain these figures is to raise the dust in a kind of wash-bottle. A wide-mouth bottle has a cork with two bent tubes fixed in it (fig. 4). One of the tubes

Fig. 4.

passes nearly to the bottom, and the other passes just below the cork. Some powder is placed in the bottle, and a stream of air sent in through A. The dust and air coming out at B are strongly charged, and on directing the stream against a charged plate very beautiful figures are obtained. The same apparatus can also be used for demonstrating the charges developed by raising dust in general, for by allowing the stream to impinge upon an insulated conductor connected to an electroscope, very strong charges can be obtained, even in a small room, but it is very difficult to determine whether the effect seen is due to the charge upon the air or upon the dust. If the current of air supplied is a gentle one, then the normal electrical effect will be seen, *i.e.* red lead will give a negative charge, but if the current is a strong one, the main effect may be that due to the charge upon the air, and red lead then apparently gives a positive charge, but the charge really comes from the air which accompanies the

dust. Pl. VI. fig. 4A shows the arrangement of apparatus. A disk of very fine wire gauze is supported upon an ebonite rod, and the streams of dust directed against it from the bottle. The wire gauze is connected to an electroscope.

Summary.

(1) Nearly all kinds of finely divided material when blown into a cloud of dust by a current of air, give rise to electrical charges upon the dust and upon the air.

(2) The nature of the charge resident upon the dust particles depends upon the chemical characteristics of the material.

(3) In general, the charge obtained upon the dust is opposite to that associated with the "ion" of the same substance when in solution, *i.e.* strongly basic bodies give NEGATIVELY charged dusts, and strongly acidic bodies give POSITIVELY charged dusts.

(4) In the case of salts the charge apparently depends on the relative strengths of the acidic and basic ions.

(5) Similarly constituted bodies give similar charges.

LIII. *A New Micromanometer.* By J. D. FRY, *Lecturer and Demonstrator in Physics in the University of Bristol* *.

THE following is an account of a new micromanometer which has been designed by the author and which is now in use in the Physics Department of the University of Bristol.

The principle of the instrument is simple. The difference of pressure to be measured is applied to the two sides of a stretched circular membrane. It is arranged that the centre of the membrane by its displacement twists a mirror which is suspended in a special manner, the pressure difference being finally indicated by the deflexion of a spot of light on a scale.

It is clear that with certain slight modifications of construction a manometer working on this principle may be adapted to the measurement of small differences of pressure at any absolute pressure. The form herein described has been designed for use at atmospheric pressure. The conditions governing the sensitiveness of a gauge of this type,

* Communicated by the Author.

FIG. 3.

FIG. 4 A.

FIG. 5.—Starch.

FIG. 6.—Sulphur.

FIG. 7.—Boracic Acid.

FIG. 8.—Aluminium.

FIG. 9.—Sifted Sulphur upon a charged surface. FIG. 10.—Sulphur on a positively charged surface.

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