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Carrier Mobility Spectra of Liquids Electrified by Bubbling

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The mobility spectra produced by bubbling water and various aqueous solutions of salt, acid, base, sugar, and soap have been investigated with an Erikson mobility tube under conditions of high resolving power. Curves of current against mobility show that for water there are five distinct negative groups of carriers having mobilities 1.80, 0.95, 0.45, 0.32, and 0.20 cm/sec. per volt/cm. There are two definite positive groups at mobilities 1.0 and 0.40 (varying between 0.44 and 0.34). Few carriers are produced with mobilities less than 0.1. Depending on the size of the bubbling capillary, the ratio of the total amount of positive electrification to negative varies from one to three (small capillary) to one to one hundred (12 mm tubing). Addition of salts to water favors production of slow carriers at the expense of fast ones; the curves degenerate to continuous distributions of mobilities from mobilities roughly 0.5 to 0.01. Medium concentrations (10^{-3} molal) produce more total electrification than distilled water, high concentrations (1 molal) less. With the addition of sugar to water, several groups of carriers appear whose mobilities lie between 0.1 and 0.001. There are large numbers of carriers in these groups, so that the total amount of electrification increases to about 12 times that for water. The use of air blasts of high humidity favors production of slow carriers, and gives heterogeneous spreads of mobilities. From new experiments on spraying water and salt solutions, some weak groups previously unobserved have been detected. Comparisons have been made between curves of bubbling and curves of spraying.

THE electrification of liquid droplets produced by spraying, bubbling, and similar methods is well known.[1–4] These phenomena depend upon the surface condition of the liquid, the presence of an electrical double layer within the surface being the important factor.[1] In a previous article by the author[4] on the mobility spectra of the charged carriers produced by spraying water and aqueous solutions, one curve was included in which the carriers were produced by bubbling. It was noted that the groups of carriers of unique mobility were somewhat more sharply defined in the case of bubbling than in the case of spraying. Accordingly, it seemed desirable to extend the data to the case of bubbling. This paper is a report of that work.

APPARATUS AND PROCEDURE

The Erikson mobility tube used for making measurement is essentially the same as that already described.[4] The bubbles are generated by a piece of thin-wall glass tubing drawn down to a capillary of 0.7 mm inside diameter. At a pressure of 19 cm of Hg, the air passed through the capillary at the rate of 77 cm³/sec. The droplets generated by the bubbling blast are blown into the Erikson tube by the bubbling blast assisted by a dry auxiliary blast of 150 cm³/sec. The main blast in the tube blows the carriers down the tube while an electric field draws the charged carriers across the tube.

Two new sizes of electrodes have been provided, one effectively 2.5×41 mm, the other 15×41 mm. The smaller electrode has improved the resolving power by roughly 50 percent over that of the old electrode, which was effectively 6×41 mm. The larger electrode has been used at distances far down the tube where intensities are weak.

The design of the bubbler, which is of glass except for a small sealed-in platinum electrode, like *D*, Fig. 1, reference 4, has been improved so that the outlet of the bubbler fits snugly over the inlet *I* (Fig. 1, reference 4). The auxiliary blast is now led through the chamber *M*, directly to the top of the bubbler. Glass wool and cotton filters (like *F*) have been placed on all three blasts ahead of the pressure regulators *AAA*.

The volume of the main air-blast has been measured in three ways, yielding: 2900 cm³/sec. by extrapolation of readings taken by a gas meter, a value that should be too high, if anything; 3200±50 cm³/sec. by a velometer; 3000 cm³/sec. from measurement by an orifice under

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[1] Lenard, Ann. d. Physik **47**, 463 (1915).
[2] Bühl, Kolloid Zeits. **59**, 346 (1932). A review.
[3] Chapman, Physics **5**, 150 (1934).
[4] Chapman, Phys. Rev. **52**, 184 (1937).

conditions of Reynolds number somewhat too low for the formula for volume to be strictly accurate. In previous work[4] the value of 2900 cm^3/sec. was used. In this paper the average of the three values is taken.

The mobility of the ions is given by the equation

$$k = Qd/wlV, \tag{1}$$

where k is the mobility of the carriers in cm/sec. per volt/cm (all mobilities mentioned in this paper are expressed in this unit); Q is the volume of air in cm^3/sec. traveling down the tube (i.e., the sum of the volumes of the main blast, the 150 cm^3/sec. auxiliary blast, and the 77 cm^3/sec. bubbling blast); d is the average distance the ions travel across the tube; w is the width of the tube; l is the distance downstream to the collecting electrode; and V is the voltage difference between the plates.

The data were taken by fixing Q and l, and varying V. For mobilities faster than 0.12 cm/sec. per volt/cm, the 2.5 mm electrode was used; l was 2.5 cm, and Q was 3260 cm^3/sec. For mobilities between 0.5 and 0.016, l was ordinarily fixed at 10 cm and the volume of the main blast was reduced until Q became 1630 cm^3/sec. For mobilities between 0.06 and 0.004, l was 20 cm and Q was 815 cm^3/sec. Slower mobilities were handled by suitable changes in l and Q. The 15 mm electrode was used at $l \geqq 10$ cm if intensities were weak. Thus the complete curves consisted of three overlapping portions. From the overlapping sections coefficients by which to multiply the ordinates could be determined, so that the curves could be drawn as continuous.

In the spraying experiments (see p. 188, reference 4), all the air in the spray chamber was at least 99 percent saturated. Because of the nature of spraying, and also because of the high humidity in the chamber, many neutral particles or large slow carriers were led into the Erikson tube. Thus it was found that moving the electrode downstream resulted in disappearance of fast carriers probably by attachment to these large particles.

In the case of bubbling, relatively few slow carriers or large neutral particles are produced. Because the dry (35 percent humid) auxiliary blast is connected directly to the top of the bubbler, the air at the outlet of the bubbler is found to be less than 65 percent humid. Evaporation can occur so that with water very few large carriers are observed. Likewise there are probably few large neutral particles. Thus moving the electrode downstream results merely in reduced intensity and a small loss of resolving power, probably due to diffusion and residual turbulences in the air-blast. The values of the mobilities, and the relative intensities, are unaffected.

EXPERIMENTAL RESULTS

The experimental results are given in Figs. 1–15, and in Tables I and II. The curves indicate current to the electrometer (representing number of charged particles, since they are believed to be singly charged[4]) as a function of the mobility of the particles, determined from Eq. (1). The ordinates of all curves are given in the same arbitrary units.

The abscissae of all curves are plotted on a logarithmic scale. It will now be shown that with this scale the *area* under the curve represents the *total charge* produced in unit time.

If y is plotted as a function of x, then $\int_a^b ydx$ equals the total area under the curve from a to b. In our case we are plotting the charge (per unit time) to the electrometer q, as a function of voltage V. We may choose to take the ordinates y as proportional to q. But if we wish to make $\int ydx$ equal to the total charge, we must *not* take the abscissae x, proportional to V, as is shown from the following reasoning.

Because of the finite width of the electrode, the carriers incident on it will always have a certain spread of mobilities. For an electrode at a fixed downstream distance l, from the inlet of the tube, the downstream width of the electrode δl, will of course be a certain fixed fraction of l. Hence, as seen from Eq. (1), the spread of mobilities of the carriers incident on the electrode will be this same fixed fraction of the mean mobility, i.e., $(k_2 - k_1)/k = \delta l/l$. Likewise, for all mobilities, the *same* fractional increase of voltage $\delta V/V$ will cause carriers to sweep from the downstream edge of the electrode to the upstream edge. Thus the reading q of the electrometer, samples the charge of the carriers in constant *fractional* increments. On the other hand, the ordinate of any curve samples the area under that curve by constant *additive* increments—that is, the area of a curve,

$$\int y dx = \lim_{\delta x \to 0} \sum y_i \delta x_i,$$

where δx_i are constant increments. Thus in our curves of q as a function of V, we must take increments of abscissae δx, proportional to fractional increments of voltage $\delta V/V$. Hence in the limit (when we draw a smooth curve instead of a series of rectangular steps side by side), we must have $dx = \text{const. } dV/V$. On integrating, $x = \text{Const. } (\log V)$, and thus we see that if we wish the area under the curve to represent the total charge produced in unit time, we must plot abscissae on a logarithmic scale.

The total amounts of positive and negative electrification have also been determined by turning off the main downstream blast and collecting all the charge on the 15 mm electrode directly opposite the inlet to the Erikson tube. These values for totals check those obtained from areas of curves. The totals, good to about five or ten percent, are given in Tables I and II.

Distilled water

Figure 1 shows the curve for ordinary fresh distilled water. The significant feature of the curve is the very definite grouping of the charge into carriers of unique mobility. Since the inlet and electrode are of finite size, a group of unique mobility is represented not by a sharp spectral line, but by a narrow band whose half-width (width at half the maximum ordinate) is 10 percent; i.e., (voltage width)/(median voltage) $= 10$ percent. The age of these carriers is about $\frac{1}{2}$ second, so that a spread of mobilities of at least an additional 10 percent is to be expected.[5, 6] Since the actual half-width of group I is 22 percent, it may be considered to be a group unique in characteristics. Its mobility is -1.8 ± 0.1 cm/sec. per volt/cm.[7] This value is not necessarily absolute, since an air-blast method is not capable of yielding accurate absolute values, although the relative values obtained by it may be good to one or two percent. Mobilities of the other groups are: II$^-$ 0.95, IIIa$^-$ 0.45, IIIb$^-$ 0.32, IV$^-$ 0.20; II$^+$ 1.0, III$^+$ 0.40 (varying between 0.44 and 0.34). Other curves definitely prove the existence of the unresolved and apparently doubtful IIIa$^-$. The total amount of negative electrification compared to the total positive is in the proportion -4.0 to $+1.0$. (See Table I.)

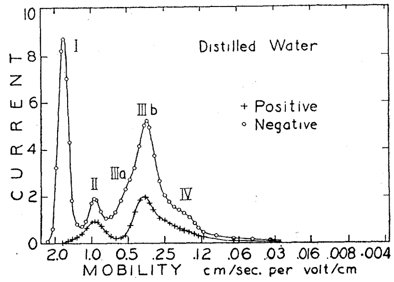

FIG. 1. Mobility spectrum produced by bubbling distilled water.

Salts

Figure 2 shows the curve for 1×10^{-5} molal potassium chloride. (The broken curve represents a portion of the negative curve for 4×10^{-5} molal, each break in the curve being an experimental point.) Groups II$^-$ and II$^+$ are weaker than for distilled water; IIIa$^-$, IV$^-$ and IV$^+$ are considerably enhanced.

Figure 3 is for 1×10^{-4} molal potassium chloride. The I and II groups are weakened further, the III groups are being lost in the tails of IV. The carriers slower than 0.12 are becoming more prominent, and the total amount of both positive and negative electrification is increasing.

In Fig. 4 for 1×10^{-3} molal potassium chloride, almost all the structure of the curves has been lost, and there remains only a broad spread of mobilities with a maximum ordinate of about 5 at mobility 0.06.

With a 10^{-2} molal solution (not illustrated), the maximum of the broad smear shifts to a mobility of about 0.03, but remains at about the same height. The positive and negative totals are equal. A solution of 0.1 molal shifts the maximum to mobility 0.016, with ordinate of about 3, so that the total amount of electrification is now being reduced by further increase of concentration. No carriers have a mobility greater than

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[5] Zeleny, Phys. Rev. **38**, 969 (1931).

[6] Loeb and Bradbury, Phys. Rev. **38**, 1716 (1931).

[7] In an abstract, Chapman, Phys. Rev. **53**, 211 (1938), because of a typographical error, this value was given as 1.07.

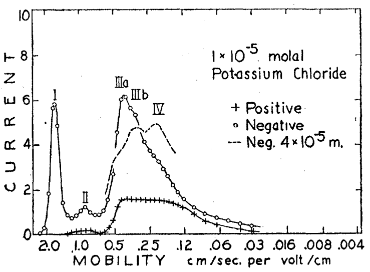

FIG. 2.

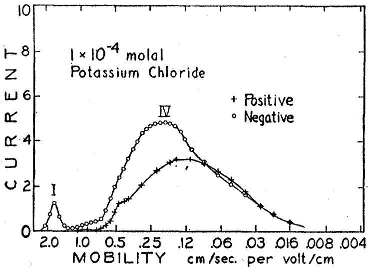

FIG. 3.

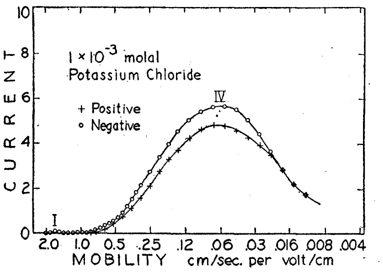

FIG. 4.

FIGS. 2–4. Mobility spectra produced by bubbling solutions of potassium chloride of various concentrations.

0.25. With one molal solution the maximum shifts to mobility about 0.008, and the totals are still further reduced. With 4 molal the trends continue.

The characteristics in the $MgSO_4$ series and also in the $AlCl_3$ series are found to be about the same as those just discussed for the KCl series. The only significant difference is that the total amount of positive electrification is proportionally greater with $AlCl_3$. (See Table I.)

Acid and base

The curves for NaOH are very similar to those of KCl, except for the fact that with NaOH the II^+ peaks are more rapidly reduced with increasing concentration. The curves for HCl and HNO_3 are different from those of KCl, particularly with regard to the II^- and II^+ peaks. The II^- peaks are weaker than for the corresponding concentration of KCl, and the II^+ peaks are strongly enhanced. This fact is brought out by Fig. 5 for 1×10^{-4} molal HNO_3. The structure of the curves persists even to a strength of 1×10^{-3} molal.

Sugar

Figures 6–9 show some of the results for sucrose. (Note the change in ordinate scale at high concentration.) The striking features of the curves are the number of distinct mobilities that are present in the negative curves, and the complete absence of fast positives. Even for 1×10^{-5} molal, II^+ is practically nonexistent, and III^+ is weak. In the negative curves it is difficult to be sure whether the slower (less well resolved and doubtless somewhat heterogeneous) groups shift gradually to lower mobilities, or whether with increasing concentration there are new groups appearing that smear the previously existing ones into their sides in such a way as to cause an apparent gradual shift of the maximum. The "reappearance" of a group at -0.06 in Fig. 9 tends to point to the latter conclusion, although probably both phenomena occur.

The total amounts of electrification increase with increasing concentrations (see Table I) until the amount of sugar in the solution is about ten percent by weight. Further increase of concentration changes the viscosity of the solution so that the decrease in the total amount of electrification can probably be ascribed to reduction of effectiveness of the bubbling mechanism.

Violence of bubbling

The regular capillary tube used to generate the bubbling was one that passed 77 cm^3 of air per second. The apparent violence of the bubbling could be considerably increased by using a capillary that passed 200 cm^3/sec. The negative curve marked "violent" in Fig. 10 was made with the 200 cm^3/sec. capillary. The chief point of interest is that the totals have been increased by a factor of about five (see Table I), and that there is a relative increase in the number of particles of mobility less than 0.12. The positive curve is not shown, but the changes in it resulting from the use of the 200 cm^3/sec. capillary instead of the 77 cm^3/sec. capillary are similar to those of the negative curve. The total amounts of negative and positive electrification have been changed from $-4/+1$ with the usual 77 cm^3/sec. capillary to $-18/+6$ (ratio 3 to 1) with the 200 cm^3/sec. capillary.

By using a tube of 12 mm inside diameter to produce the bubbles (still using 77 cm^3/sec. of air), the bubbling appeared to be very gentle and

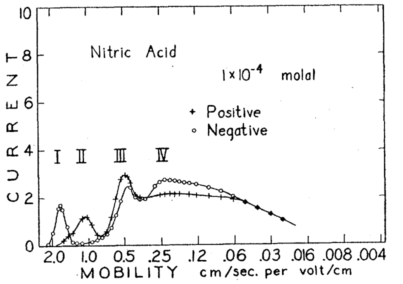

FIG. 5. Mobility spectrum produced by bubbling 1×10^{-4} molal nitric acid.

uniform. The curve marked "gentle" in Fig. 10 was made with the 12 mm tube. Although the amount of negative charge was reduced to about $\frac{1}{6}$ of the usual value (Fig. 1), the ratio of negative to positive was certainly greater than one hundred to one. No positive electrification could be detected.

Effect of age

As mentioned under "Apparatus and Procedure," no change in the distilled water curves was noted when the measurement was made far downstream. Likewise, doubling the age of the particles before they entered the Erikson tube produced no significant change other than about a 25 percent loss of the faster particles due to longer time for diffusion.

Humidity and temperature effects

Humid air.—Under normal conditions of operation, the relative humidity of the various air blasts was about 35 percent or less, and their temperature was the same as that of the room (i.e., about 23°C). Usually the equilibrium temperature in the bubbler was about 6°C below room temperature.

A certain amount of control over the humidity in the bubbler could be obtained by turning off the dry (35 percent humid) auxiliary blast. Thus the air in the bubbler had all been bubbled so that its humidity was over 95 percent. As a result of this operation, the number of carriers of both signs of mobilities less than 0.25 was roughly doubled. As can be seen from Fig. 1, there are few carriers in this range so that doubling their number did not greatly affect the total amount of charge. In fact, the loss in the number of carriers of mobilities greater than 0.25 (particularly in groups I^- and $IIIa^-$) was more than sufficient to compensate for the increased number of slow carriers, so that the total amounts of charge were reduced by about 10 percent (see Table I).

TABLE I. *Total amounts of negative and positive charge produced by bubbling the solutions indicated. The same units are used throughout Tables I and II.*

Distilled Water (Fig. 1)	−4.0	+1.0
KCl 1×10^{-5} molal (Fig. 2)	−4.7	+1.7
KCl 1×10^{-4} molal (Fig. 3)	−5.3	+3.1
KCl 1×10^{-3} molal (Fig. 4)	−7.5	+7.2
KCl 0.01 molal	−7.7	+7.7
KCl 0.1 molal	−5.0	+5.0
KCl 1 molal	−2.2	+2.2
KCl 4 molal	−1.5	+1.5
$AlCl_3$ 3×10^{-5} molal	−6.5	+3.5
$AlCl_3$ 3×10^{-3} molal	−8.0	+12
$AlCl_3$ 0.03 molal	−6.0	+8.0
$AlCl_3$ 0.3 molal	−4.0	+4.0
NaOH 1×10^{-5} molal	−4.4	+1.4
NaOH 1×10^{-4} molal	−6.3	+3.0
HNO_3 1×10^{-5} molal	−3.9	+1.4
HNO_3 1×10^{-4} molal (Fig. 5)	−3.2	+3.1
HNO_3 1×10^{-3} molal	−3.4	+3.4
Sucrose 3×10^{-6} molal (Fig. 6)	−5.4	+1.7
Sucrose 3×10^{-5} molal	−7.5	+2.7
Sucrose 3×10^{-4} molal (Fig. 7)	−11.7	+6.8
Sucrose 3×10^{-3} molal (Fig. 8)	−18	+14
Sucrose 0.03 molal	−28	+21
Sucrose 0.3 molal (Fig. 9)	−35	+31
Sucrose 0.8 molal	−25	+25
Sucrose 2 molal	−5.5	+6.5
Water, violent, 200 cc/sec., auxiliary off	−25	+7.0
Water, violent, 200 cc/sec., auxiliary on (Fig. 10)	−18	+5.5
Water, normal, 77 cc/sec., auxiliary off	−3.5	+0.95
Water, gentle, 12 mm tube, auxiliary on (Fig. 10)	−0.7	+0.00
Water, 99 percent humidity in aux., bubbling temp. at equilibrium 6°C below room temp.	−6.0	+1.7
Water, 99 percent humidity in aux., bubbling at room temp. (Fig. 11)	−8.2	+2.6
Water, supersaturated in aux. (Fig. 12)	−10	+3.5
Hot water 55°C, dry aux. (Fig. 13)	−9.0	+1.2
Hot water 80°C, dry aux.	−11	+0.6
Sodium Stearate 3×10^{-6} molal	−4.5	+1.3
Sodium Stearate 1×10^{-5} molal	−7.0	+1.8
Sodium Stearate 1×10^{-4} molal	−8.0	+4.5
Sodium Stearate 1×10^{-3} molal	−12	+12

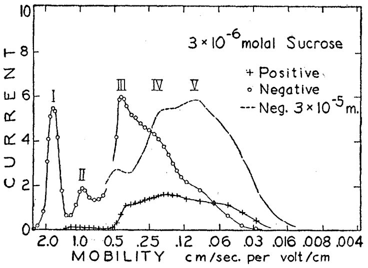

FIG. 6

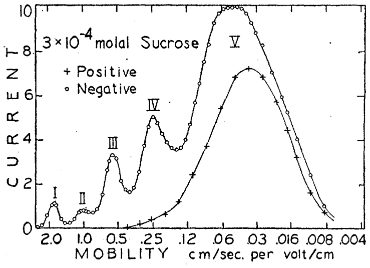

FIG. 7

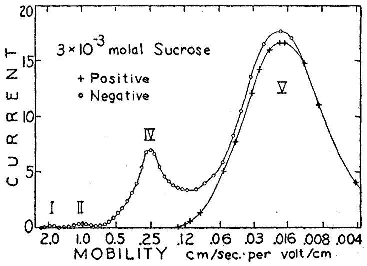

FIG. 8

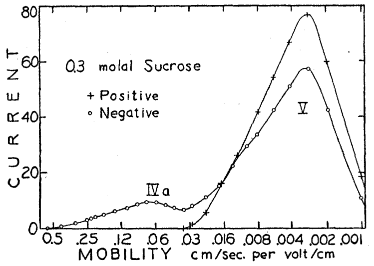

FIG. 9.

FIGS. 6–9. Mobility spectra produced by bubbling solutions of sucrose of various concentrations.

By bubbling the air to the auxiliary through hot water and filtering out all the electrification, a supply of strictly 100 percent humid air was obtained. By mixing this moist air with a certain amount of dry air, a fair control over the humidity was obtained. No noticeable changes in the curves occurred unless the humidity was over 90 percent. The humidity of the auxiliary was the controlling factor in the humidity experiments. Humidifying the other two blasts had little effect.

Figure 11 shows a distilled water curve made with bubble temperature 24.5°C, the room temperature 24.6°C, and the temperature of both the wet and dry bulb thermometers of the auxiliary 24.0°C. The humidity in the auxiliary was probably a trifle under 100 percent, since there was no condensation of moisture on a dry surface. It is seen that group I^- is weaker than in Fig. 1, II^- is smeared out, $IIIa^-$ virtually missing, $IIIb^-$ strong, IV^- strong, and that there are considerable numbers of carriers of mobility less than 0.12. II^+ has shifted to a lower mobility, as has III^+. There are also considerable numbers of slow positive carriers. The total amounts of both positive and negative electrification have nearly doubled. It is likely that some of this increase has come from carriers that evaporated slowly (and hence were of low mobility), so that they did not diffuse to the walls of the bubbler as they did in the normal dry-air experiments.

Moist air.—By using only moist air, so that condensation was actually occurring in the *auxiliary* blast, the curves in Fig. 12 were obtained. Remarks made in "Apparatus and Procedure" about the maintenance of the shape of curves when the electrode is moved downstream do not apply to this humidity experiment. In plotting the curves in Fig. 12, the ordinates have already been multiplied by the usual dry-air coefficients necessary to obtain overlapping curves (as mentioned in "Apparatus and Procedure").

The reason the curves in Fig. 12 do not overlap is that evaporation of the carriers has been occurring in the dry (35 percent humid) main blast of the Erikson tube. The carriers in curves *AA* have been in the dry blast for 0.013 second; those in *BB*, 0.11 second; and those in *CC*, 0.44 second. It is seen that the longer the time the carriers spend in the dry blast, the greater the number of fast carriers, and the fewer the number of slow ones. Because of condensation on the insulation, it was impossible to obtain results when moist air was used in the main blast.

Temperature.—With dry (35 percent humid) air used in all blasts, if the water in the bubbler is heated, there is an increase in negative electrification due to the reduction of viscosity of the water changing the bubbling mechanism. The change of mechanism is made evident by the fivefold increase in the amount of water splattered out of the bubbler. With increase in temperature, the total amount of positive electrification first increases slightly, and then decreases. (For examples, see Table I.) Group II^- is enhanced by heating, and IIIa$^-$ is nearly eliminated. Groups II$^+$, III$^+$, and IIIb$^-$ move toward lower mobilities. Fig. 13 shows a typical curve from this set.

Soap

Solutions of sodium stearate of various strengths were investigated in order to test the effect of the lowering of surface tension. Surprisingly enough, the changes produced were relatively slight. Group II$^-$ was trebled in magnitude in weak solutions (10^{-5} mole per liter). Stronger solutions (10^{-3} molal) virtually eliminated the I and II groups, although not so effectively as salt. The total amount of electrification from the strongest solution that could be investigated (3×10^{-3} molal) showed about twice as much electrification as salt of the same concentration. In half-width, the slowest stearate group resembled the slowest sugar group, rather than the broad maximum of salt.

Normal ions

By placing a radioactive source in the inlet, "normal ions" could be led into the Erikson tube. The negative ion peak came at mobility 1.66 with half-width of 34 percent. The positive group came at 1.15, half-width 46 percent. Introducing 99 percent humid air gave $k^-=1.64$, half-width 23 percent, and $k^+=1.11$, half-width 38 percent. In each case there was a disappearance of some of the faster carriers in the group, resulting in a slight decrease in mobility of the peak. Immediately afterward, bubbling peaks were made with dry (35 percent humid) air, yielding: $\mathrm{I}^-=1.80$, half-width 21 percent; $\mathrm{II}^-=0.95$; $\mathrm{II}^+=1.0$. Spraying peaks were then observed; negative 1.67, half-width 41 percent; and positive about 1.52 and 0.95 (see next section).

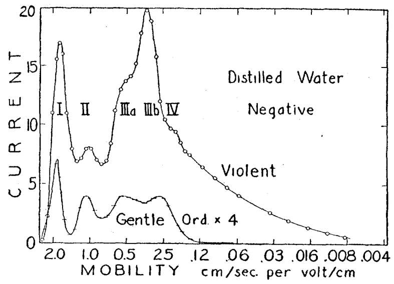

FIG. 10. Mobility spectra for negative carriers produced by violent and gentle bubbling (see text). The ordinates of the "gentle" curve have been multiplied by 4.

Spraying

An attempt was made to correlate the groups previously observed[4] by spraying, with the present bubbling groups. The improved resolving power of the 2.5 mm electrode brought out a few previously undetected weak groups. Figs. 14–15 show curves obtained by spraying distilled water and some KCl solutions. The groups observed are of mobilities -1.67, approximately -0.85, -0.44, -0.28, a broad maximum about -0.06 with a gradual tailing off down to -0.002; $+1.52$, $+0.95$, $+0.70$, $+0.49$, $+0.28$, and a broad maximum at about $+0.06$. The curves for sprayed KCl solutions show which of the groups shift into the peaks previously observed with spraying. For the negative carriers there is a one to one correspondence between the sprayed groups and the bubbled groups; the mobilities in the case of spraying are only slightly less than in

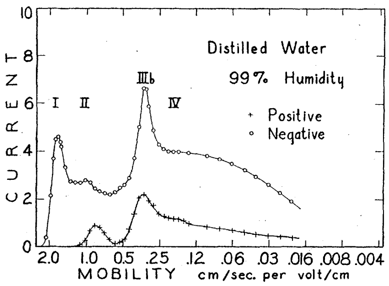

FIG. 11. Mobility spectrum of distilled water produced by bubbling in the presence of approximately 99 percent humid air (see text).

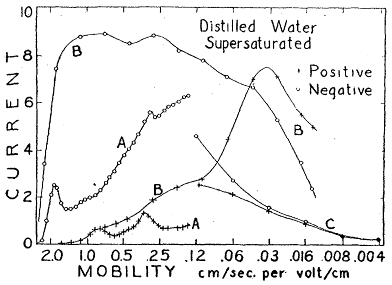

FIG. 12. Mobility spectrum of distilled water produced by bubbling in the presence of supersaturated air (see text). Curves *AA* made at $l=2.5$ cm, $Q=3260$ cm^3/sec. with 2.5 mm electrode. Curves *BB*, $l=10$, $Q=1630$, 15 mm electrode. Curves *CC*, $l=20$, $Q=815$, 15 mm electrode.

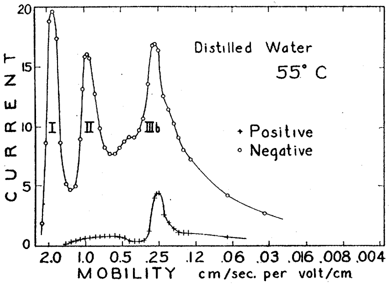

FIG. 13. Mobility spectrum produced by bubbling distilled water at 55°C.

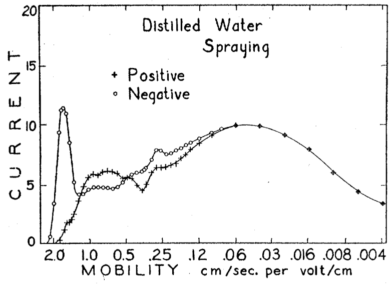

FIG. 14. Mobility spectrum produced by spraying distilled water.

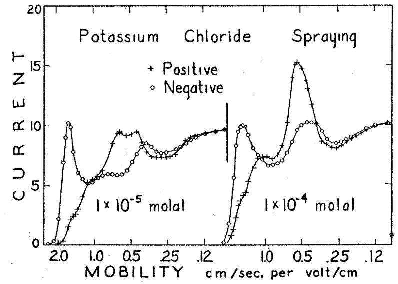

FIG. 15. Mobility spectra produced by spraying solutions of potassium chloride.

the case of bubbling. The equality of corresponding mobilities is quite marked with the bubbling curves made under conditions of high humidity (when conditions more nearly resemble the humid spray atmosphere). For the positive carriers, there are apparently no bubbling analogues to the groups +1.52, +0.70, and probably +0.49; yet in the bubbling curves, the positive groups are not so sharp as the negative groups, and it is quite possible that traces of these positive groups do exist. For instance, the high mobility side of the II$^+$ peak is particularly gradual in dropping off to zero. It is almost certain that a weak group could be found in this region if the intensities were five times as great. Such a positive mobility of 1.52 corresponds very nearly to that of the "normal" positive ion in absolutely *dry* air. New measurements on the amounts of total electrification produced by spraying salt solutions of concentrations up to 1 molal are given in Table II. These results confirm previous conclusions regarding the decrease of total amounts of electrification with increasing concentration in solutions more concentrated than 10^{-4} molal.[4]

TABLE II. *Total amounts of negative and positive charge produced by spraying.*

Distilled water (Fig. 14)	−38	+38
KCl 1×10^{-5} molal (Fig. 15)	−40	+40
KCl 1×10^{-4} molal (Fig. 15)	−42	+43
KCl 0.01 molal	−11	+11
KCl 1 molal	−2	+2

In conclusion, the writer wishes to thank Professor L. B. Loeb, under whose direction the experiments were carried out, for his continual interest and invaluable suggestions concerning all phases of the work.