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2. *The mobility of positive ions in flames.*

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## STRAIN AND DIAMAGNETIC SUSCEPTIBILITY

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### ABSTRACT

The magnetic susceptibility of copper and silver wires has been measured by the Gouy method before and after various annealing processes. Also, the susceptibility has been measured before and after straining specimens beyond the elastic limit, the strains being either twists or stretches. The susceptibilities are found to be increased by as much as 20 percent for copper and 3 percent for silver by annealing at red heat for 15 minutes in an atmosphere of  $\text{CO}_2$ . This increase is probably due to release of occluded gases or to oxidation or recombination of impurities. Straining the specimens beyond the elastic limit is found to produce no measurable change of susceptibility. Francis Bitter has observed a large effect due to straining these metals beyond the elastic limit. The reason for Bitter's results is not clear, but it is pointed out that no effect is to be expected in copper, at least, because crystals of this metal are isotropic magnetically and have no observable magnetostriction.

RECENTLY Francis Bitter<sup>1</sup> has made the surprising and important observation that annealed copper (impure, paramagnetic) and silver wires suffer a very appreciable change of magnetic susceptibility when strained beyond the elastic limit. This result is surprising for the following reasons. Straining a wire beyond the elastic limit may have the effect of breaking up large crystals into smaller ones. Slipping occurs along cleavage planes, crystal boundary planes are distorted, segregated impurities are redistributed, and new orientations may result for the axes of the tiny crystals. In addition to these effects certain parts of the wire will be left elastically extended, other parts elastically compressed as a result of the unequal slipping of various sections of the wire. These residual strains in a wire have for years been a source of annoyance to users of the Eötvös torsion balance.

It appears, therefore, that the change of susceptibility of a wire when stretched might be explained by two factors: (1) the orienting effect on the small crystals, and (2) the setting up of a strained condition in the wire. In the case of copper the first factor must be ruled out because Montgomery<sup>2</sup> has shown that copper crystals are isotropic magnetically. The second factor is also inadequate for the following reason: the reciprocal relations between strain and magnetization may be expressed by the equation  $\partial I/\partial p = \partial e/\partial H$ , where  $I$ ,  $H$ ,  $p$ , and  $e$  are, respectively, intensity of magnetization, magnetic field, applied stress, and strain  $\partial l/l$ . The last two quantities are along the  $H$  direction. This equation is based on thermodynamical principles and according to Honda<sup>3</sup> has been verified experimentally even in the case of iron

<sup>1</sup> Francis Bitter, Phys. Rev. **36**, 978 (1930).

<sup>2</sup> Carol G. Montgomery, Phys. Rev. **36**, 498 (1930).

<sup>3</sup> Honda, Magnetic Properties of Matter, p. 46.

and nickel, where hysteresis would tend to make the equation inapplicable. It should hold accurately where hysteresis is negligible, as in copper. In copper, however, magnetostriction is so small that it has never been detected; thus  $\partial e/\partial H$  is negligible and therefore  $\partial I/\partial p$ , or  $H\partial K/\partial p$  must be very small. The absence of magnetostriction in copper thus shows that the susceptibility  $K$  is unaffected by applied pressures. Hence the second factor given above must be ruled out as an explanation. Accepting Bitter's experimental results, the only conclusion appears to be that the above description of the processes involved in stretching a wire is incomplete.

Accordingly, a series of tests on the effect of strain on the susceptibility of copper and silver was made. As in Bitter's experiments, the Gouy method was used. An analytical balance was mounted about half a meter above an electromagnetic with pole-pieces (truncated cones) 1 cm in diameter and 4 mm apart. The specimen, in the form of a wire about 15 cm long and 2 or 3 mm in diameter, was suspended from one arm of the balance by a silk thread, the lower end of the wire being centered with respect to the pole-pieces. The force on the wire is given by the equation  $F = KH^2a/2$  where  $K$ ,  $H$ , and  $a$  are the volume susceptibility, magnetic field intensity at the lower end of the wire, and cross-sectional area of the sample, respectively.

When the specimen was suspended 15 cm above the poles of the magnet the balance was not deflected by a measurable amount. Therefore the above equation requires no correction for the field at the top of the specimen. All samples were diamagnetic.

The first set of results was obtained for commercial copper wire about 2.6 mm in diameter. Forces on the samples were measured; they were then twisted beyond the elastic limit by various amounts and the forces again measured. A representative part of these results is shown in Table I. These

TABLE I. *Effect of twist on susceptibility.*

Sample	$F_1$ dynes	Angle of twist	$F_2$ dynes	$\Delta F$
1	7.44	0	7.53	+ .09
2	7.15	$\pi/2$	7.26	+ .11
3	7.20	$\pi$	6.95	- .25
4	7.08	$2\pi$	7.11	+ .03
4	7.11	$30\pi$	7.00	- .11

wires did not all have the same diameter, so the forces are different for the different samples. The samples had been well annealed, first in a flame, then in an electric furnace in air. The oxide coating consequent to annealing was removed by sand-papering the surface. It appears that the values of  $\Delta F$  are within the limits of experimental error. The average value of  $\Delta F$  is  $-0.03$  dyne and there are both positive and negative values. Furthermore in this experiment it is doubtful whether  $F$  could be determined accurately to more than 0.2 dyne. We conclude therefore that  $K$  is unaffected by twisting the copper wire greatly beyond the elastic limit. The average specific susceptibility cal-

culated for these samples is  $0.5 \times 10^{-7}$ . For pure copper Montgomery gives  $0.85 \times 10^{-7}$ .

A series of experiments on stretched copper wire was then made. The order of magnitude of  $F$  (corrected for changes in diameter) was about the same as in the set of observations shown in Table I. This degree of accuracy was at first considered sufficient, since Bitter got  $\Delta F$  as large as  $\frac{1}{2}F$ ; but later, pole pieces with larger areas (in order to minimize errors of adjusting the specimen between the pole-pieces) were put on the electro-magnet, and crossed telescopes fastened to its frame to provide accurate control over the position of the specimen. The measurement of the force on a specimen which had been removed and replaced could then be repeated to 0.1 dyne.

The preliminary work showed that annealing a copper wire affected its susceptibility. For example, the force on a specimen was measured, it was heated to redness in  $\text{CO}_2$  for about three minutes, cooled slowly, and the force again measured. Successive forces, each determined after a three minute heat treatment, were  $-6.0$ ,  $-6.5$ ,  $-7.0$ ,  $-7.3$ , and  $-7.3$  dynes. Similar effects due to annealing have been obtained by Davies and Keeping<sup>4</sup> for copper-antimony alloys. They attribute the phenomenon to changing of the nature of the compounds of copper and antimony. Some samples in the present experiments were heated to a bright red heat in a vacuum, and gave off a gas which, at ordinary pressure, had about half the volume of the copper. The nature of this gas is not known. Therefore it was possibly the presence of impurities or freeing of adsorbed gas which produced the increase of  $F$  noted above. The foregoing results indicate that an annealing at red heat for about fifteen minutes is necessary in order to secure the final stable value of the susceptibility. Therefore all further annealings were done in  $\text{CO}_2$ , holding the specimen above red heat for fifteen minutes and allowing it to cool slowly. All further cleanings are by immersion in boiling  $\text{HCl}$  for about two minutes, unless otherwise stated.

A second specimen of copper which was slightly paramagnetic when uncleaned was obtained. With its surface sand-papered  $F=0.0$  dyne. Annealed,  $F=-3.04$  dynes. This is sample *A* in Table II. Another sample was not annealed, but was cleaned with acid and a value  $F=-5.1$  dynes found; some of the surface was then removed with sand-paper and  $F$  found to be  $-5.4$  dynes. Thus it appears that paramagnetic impurities were removed from the surface by sand-papering. It is therefore possible that some of the increase of  $F$  at annealing is due to the removal (possibly by oxidation) of impurities at or near the surface. When thoroughly annealed this specimen had a value of  $F=-6.4$  dynes.

Chemically pure samples of copper and silver were obtained from Baker and Company. These are shown as *C* and *D*, respectively, in Table II. The procedure with each sample of Table II was as follows: the force  $F$  was measured (except sample *B*); the wire was annealed and cleaned, and its force  $F_1$  again measured. It was then stretched till its length changed permanently

<sup>4</sup> G. W. Davies and E. S. Keeping, *Phil. Mag.* **7**, 145 (1929).

by the fraction  $\Delta l/l$ , cleaned, and the force  $F_2$  again measured. Again it was annealed and cleaned, and the force  $F_3$  again measured. The forces in this table are shown in mg, the units in which they were measured. The  $d$ 's are diameters of the samples. Multiplying by  $(d_1/d_2)^2$  corrects  $F_2$  for the change in cross-sectional area consequent to stretching; so  $F_1 - F_2(d_1/d_2)^2$ , shown in the table as  $\Delta F$ , is a measure of the change of  $K$  when the sample is stretched.

TABLE II. *Effect of stretching on susceptibility.*

Sample	$F$ mg	$F_1$ mg	$d_1$ mm	$\Delta l/l$	$F_2$ mg	$d_2$ mm	$F_3$ mg	$F_2(d_1/d_2)^2$ mg	$\Delta F$ mg	$K \times 10^6$
A	0.0	3.1	2.61	.10	2.9	2.48	—	3.2	+0.1	-0.22
B*	5.4	—	2.58	.12	4.7	2.43	5.7	5.3	-0.1	-0.48
C	8.0	9.2	3.00	.10	8.6	2.85	8.5	9.4	+0.2	-0.51
C'	—	8.6	2.85	.195	7.2	2.61	7.2	8.6	0.0	-0.51
D	28.7	30.0	3.00	.235	24.3	2.70	24.3	29.9	-0.1	-1.62

\* Note: This specimen was annealed in a flame for about one minute at less than red heat before  $F$  was obtained. It was given no further annealing before being stretched. Specimen  $C'$  is the specimen  $C$  after all the data following  $C$  were obtained. ( $F_1$  for  $C'$  should be the same as  $F_3$  for  $C$  except for experimental error.)

Since  $\Delta F$  is within the limit of experimental error it seems reasonable to conclude that  $K$  is unaffected by the stretch. Also, since  $F_3$  is the same as  $F_2$  (except for  $B$ ), we conclude that annealing a wire of copper or silver which has been hardened by severe stretching does not affect its magnetic susceptibility, provided proper heat treatment has stabilized the wire magnetically before it is strained.

The data on  $B$  show that straining a wire which has been imperfectly annealed does not affect its susceptibility. In these experiments the specimens were given permanent strains as large as were used in Bitter's experiments, and the accuracy of measurement was sufficient to detect an effect at least 1/10 as large as Bitter observed. In no case has Bitter's effect been detected. Furthermore, as pointed out in the introduction, there is reason for disbelieving in the reality of the effect because of the absence of magnetostriction in copper and silver.

The conclusion may therefore be drawn that the magnetic susceptibility of copper and silver is not appreciably affected by straining wires of copper and silver beyond the elastic limit. The reason for Bitter's results is not evident.

It is indeed a pleasure to thank Dr. C. W. Heaps for many helpful suggestions and criticisms throughout the investigation.

*Thesis*

*The Mobility of Positive Ions in Flames*

*by*

*H. Eugene Bauta*

*Rice Institute*

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## THE MOBILITY OF POSITIVE IONS IN FLAMES

By H. E. BANTA

## ABSTRACT

**Mobility of positive ions of K, Rb and Cs in the Bunsen flame.**—The mobility was calculated from measured values of the current density, cathode drop of potential, and the thickness of the layer at the cathode in which the potential varies rapidly. The excess of ionization over recombination in the layer was assumed to be proportional to  $(1-x/x_1)^m$ , where  $x$  is the distance from the cathode,  $x_1$  the thickness of the layer at the cathode, and  $m$  is a constant. J. J. Thomson supposed that  $m=0$ , and P. E. Boucher took  $m=1$ . The value calculated for the mobility depends on the value assumed for  $m$ . The results give, with  $m=2$ , a value of 1.8; with  $m=3$ , a value of 1.07 cm/sec. per volt/cm for the mobility. It is found that the mobility is the same for salts of Rb, Cs, and K, and that it does not depend on the concentration of the salt. A small increase of mobility with electric intensity is indicated by the results.

THE mobility of the positive ions has been measured by several physicists<sup>1</sup>, and is now believed to be about one cm per sec for one volt per cm; but the possible error of this estimate is very large. The following paper contains an account of a series of experiments the object of which was to determine the mobility of the positive ions in a flame. The method used is similar to that quite recently employed by P. E. Boucher.<sup>2</sup> Boucher observed the variation of the potential near the electrode, and so obtained the thickness of the layer or sheath at the cathode in which the potential varies rapidly. Using a slightly modified form of J. J. Thomson's<sup>3</sup> theory of the variation of the potential in the sheath, the mobility of the positive ions can be calculated in terms of the thickness of the sheath, the current density, and the drop of potential across the sheath.

## THEORY

The theory of the variation of the potential between two electrodes in an ionized gas was given by J. J. Thomson. He showed that there was a central region of uniform electric intensity, with a sudden large increase of the electric intensity near both the electrodes. The theory may be deduced from his well known equation  $d^2X^2/dx^2 = 8\pi e(1/k_1 + 1/k_2)(q - an_1n_2)$ , where  $X$  is the electric intensity,  $x$  the distance from the surface of the positive electrode,  $k_1$  and  $k_2$  are the mobilities of the positive and negative ions respectively,  $q$  the number of molecules ionized per cc per sec,  $a$  the coefficient of recombination, and  $n_1$  and  $n_2$  the number of positive and negative ions per cc.

Let  $x_1$  and  $x_2$  be the thicknesses of the sheaths at the positive and negative electrodes respectively, and  $d$  the distance between the electrodes. J. J.

<sup>1</sup> H. A. Wilson, Phil. Trans. 216, 63 (1915); Andrade, Phil. Mag. 23, 865 (1912); Phil. Mag. 24, 15 (1912).

<sup>2</sup> P. E. Boucher, Phys. Rev. 31, 833 (1928).

<sup>3</sup> J. J. Thomson "Conduction of Electricity through Gases," Chaps III and IX.

Thomson assumed that the recombination  $an_1n_2$  was equal to zero from  $x=0$  to  $x=x_1$ , and from  $x=d-x_2$  to  $x=d$ . From  $x=x_1$  to  $x=d-x_2$ ,  $X$  is constant and  $d^2X^2/dx^2=0$ ; so  $q-an_1n_2=0$ . Also  $dX/dx=4\pi e(n_1-n_2)=0$ , and  $n_1=n_2=n$ , the recombination balancing the ionization.

J. J. Thomson's assumption that there is no recombination in the sheaths makes the value of  $q-an_1n_2$  discontinuous at the surface of the sheaths, since he assumes  $q-an_1n_2=q$  from  $x=0$  to  $x=x_1$  and  $q-an_1n_2=0$  from  $x=x_1$  to  $x=d-x_2$ . P. E. Boucher therefore assumed  $q-an_1n_2$  is equal to  $q(1-x/x_1)$  from  $x=0$  to  $x=x_1$ ,  $q-an_1n_2=0$  from  $x=x_1$  to  $x=d-x_2$ , so avoiding the discontinuity at  $x=x_1$ . This assumption, however, makes  $(d/dx)(q-an_1n_2)$  discontinuous at  $x=x_1$ . It seems better, therefore, to assume  $q-an_1n_2=q(1-x/x_1)^m$ , where  $m$  is an unknown constant.

Thus  $\int_0^{x_1}(q-an_1n_2)dx=q\int_0^{x_1}(1-x/x_1)^m dx=qx_1/(m+1)$ . But  $\int_0^{x_1}(q-an_1n_2)dx=nk_1X_0$ , where  $X_0$  is the uniform electric intensity between the sheaths. Thus  $qx_1/(m+1)=nk_1X_0$ . Since  $i$ , the current density, is

$$Xe(n_1k_1+n_2k_2), \quad nX_0=i/[e(k_1+k_2)],$$

and

$$qx_1/(m+1)=ik_1/[e(k_1+k_2)].$$

Thus

$$\begin{aligned} q &= ik_1(m+1)/[ex_1(k_1+k_2)], \\ d^2X^2/dx^2 &= 8\pi eq(1-x/x_1)^m(1/k_1+1/k_2) \\ &= 8\pi i(m+1)(1-x/x_1)^m/x_1k_2. \end{aligned}$$

Integrating,  $dX^2/dx = -8\pi i(1-x/x_1)^{m+1}/(k_2) + C_1$ . At  $x=x_1$ ,  $X=X_0$ , and  $dX_0^2/dx=0$ ; so  $C_1=0$ . Integrating again,  $X^2=8\pi ix_1(1-x/x_1)^{m+2}/[k_2(m+2)] + C_2$ . At  $x=x_1$ ,  $X=X_0$ , a small constant quantity. Neglecting it,  $X^2=8\pi ix_1(1-x/x_1)^{m+2}/[k_2(m+2)]$ .

Let  $V_1$  be the potential drop across the sheath at the positive electrode, and  $V_2$  the drop at the cathode. Then

$$\begin{aligned} V_1 &= \int_0^{x_1} X dx = \{8\pi ix_1/[k_2(m+2)]\}^{1/2} \int_0^{x_1} (1-x/x_1)^{(m+2)/2} dx \\ &= [2/(m+4)] \{8\pi ix_1^3/[k_2(m+2)]\}^{1/2} \end{aligned}$$

In the same way it may be shown that

$$V_2 = [2/(m+4)] \{8\pi ix_2^3/k_1(m+2)\}^{1/2}.$$

Thus, if the excess of ionization over recombination inside the sheaths can be represented by  $q-an_1n_2=q(1-x/x_1)^m$ , the mobility of the positive ions is proportional to  $ix_2^3/V_2^2$ , whatever the value of  $m$ . The variation of the mobility with the concentration of the salt vapor and with the nature of the metal can therefore be determined.

#### APPARATUS AND PROCEDURE

The apparatus used is shown in Fig. 1. The flame used was of the Bunsen type, and was obtained by burning a mixture of natural gas, air, and spray



from a salt solution. The burner (*B*) consisted of 16 quartz tubes, arranged in three rows and cemented into a brass base. The air and gas were mixed in a Guoy sprayer (*S*). Air came from a compressed air supply, which gave a fairly constant pressure of 10 cm of mercury. To exclude any error that might arise from evaporation of the salt solution the air and gas were bubbled through water in large carboys (*C*). The carboys also served in smoothing out pressure irregularities.

The pressure of the natural gas was held constant by a pressure regulator (*R*) similar to that used by H. A. Wilson.<sup>4</sup> When the gas pressure mounted above the steady value desired, the inverted beaker (*F*) rose, and the mercury in the valve (*D*) closed the supply tube. When the pressure subsided to its normal value the supply tube was again opened. The pressure output of the

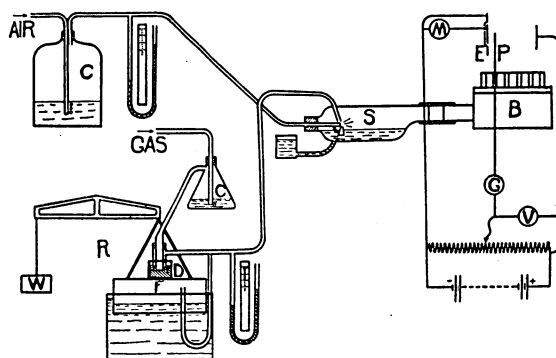


Fig. 1. Diagram of apparatus and electrical connections.

regulator was adjusted by varying a weight (*W*). The pressure used was 1 cm of water. The salt solution was introduced through a tube in the bottom of the sprayer. In this way the level of the solution inside the sprayer was kept constant.

The distribution of potential in the flame was determined by means of a very small platinum-rhodium wire (*P*), encased, except for a tip of about 0.5 mm, in a quartz tube. This tube was drawn down to a very small diameter at the tip, and was mounted on a support with an adjustable vernier scale, not shown in the diagram.

Fig. 1 shows the electrical connections. Here, *M* is a micro-ammeter, *V* a voltmeter, and *G* a high-sensitivity galvanometer shunted by a 0-50000 ohm variable resistance. The negative electrode (*E*) was a circular disk made of sheet platinum of area 1.86 sq. cm. A guard-ring of the same material shielded this electrode at sides and back, so that the current density is given by the ratio of the total current, recorded by the micro-ammeter, to the area of the front of the electrode. The other electrode was a spiral of platinum wire, about 4 cm from the first. An optical pyrometer gave the temperature of the cathode to be 1200°K, and the probe's highest temperature was 1550°K.

<sup>4</sup> H. A. Wilson, Phys. Rev. 3, 375 (1914).

The experimental procedure consisted in observing the potential difference between the probe and the anode when the slider carrying the probe was set so that the probe current was zero. The probe is assumed to be at the same potential as the flame gases very near its tip. Thus, with constant potential and current between the two electrodes, the potential of the flame at any distance from the cathode could be obtained. By plotting the probe potential against its distance from the cathode, the thickness of the sheath around the cathode could be obtained. This is  $x_2$ ; knowing the current and the potential at  $x_2$ ,  $k_1$  can be calculated.

### EXPERIMENTS

I. *Variation of the mobility with the concentration.* Solutions of KCl were sprayed into the flame, and measurements of the current, the sheath thickness, and the potential difference between the electrodes were made. The potential distribution curves for several concentrations are shown in Fig. 2. One volt

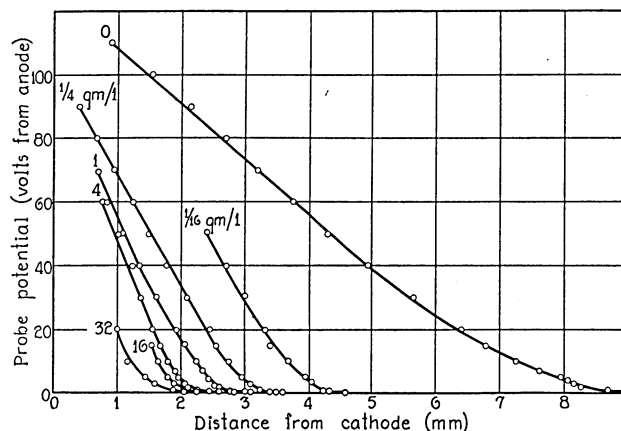


Fig. 2. Potential distribution in flame for several concentrations of KCl.

was taken as the potential at the edge of the sheath, since at about this reading the potential began to increase very rapidly as the probe approached the cathode. The results are shown in Table I;  $k$  is the solution concentration,  $x_2$  the sheath thickness,  $I$  the total current, and  $V_2$  the potential drop across the sheath.

TABLE I. *Current, sheath thickness and potential difference between electrodes for several concentrations of KCl*

$k$ gm/l	$x_2$ cm	$V_2$ volts	$I \times 10^6$ amps	$10^{12} \times I x_2^3 / V_2^2$
0	0.87	132	0.146	5.52
1/16	0.425	139	1.35	5.36
1/4	0.33	130.5	2.7	5.70
1	0.27	132	5.0	5.68
4	0.225	125	8.0	5.83
16	0.21	142	13.0	5.94
32	0.185	142	19.0	5.94

If a value be assumed for  $m$  it is possible to calculate  $k_1$ , the mobility of the positive ions, from these results. If  $m = 1$ ,  $k_1 = 32\pi ix_2^3 / (75 V_2^2)$ ;  $i$  was taken to be the total current divided by the area of the electrode. Thus the mobility of the positive flame ions is 3.5 cm per sec. for one volt per cm (this is for distilled water sprayed into the flame). The mean of the other results, for  $k = 1/16$  to 32 gms per liter, gives  $k_1 = 3.7$  cm per sec. This difference is well within the range of experimental error, as is all the variation in the mobility with the concentration.

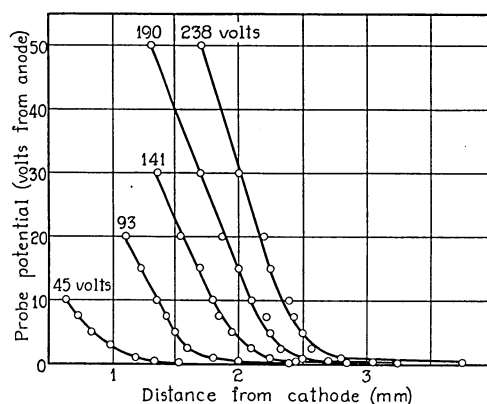


Fig. 3. Potential distribution in flame for several differences of potential between electrodes.

II. *Variation of mobility with potential.* A solution of KCl, concentration 4 gm per liter, was sprayed into the flame, and a set of readings of  $I$ ,  $x_2$ , and  $V_2$  was made for potential differences between the electrodes from 45 to 235 volts.  $X$  was obtained as has been explained previously; the potential distribution curves are shown in Fig. 3. The results are shown in Table II.

TABLE II. *Current and sheath thickness for various applied potentials in a KCl flame, concentration 4 gm/liter*

$x_2$ cm	$V_2$ volts	$I \times 10^6$ amps	$10^{12} \times I x_2^3 / V_2^2$
0.13	44	4.0	4.54
0.19	92	5.7	4.62
0.24	140	7.3	5.15
0.265	188	9.7	5.11
0.29	236	12.5	5.47

In these cases the sheath thicknesses were arrived at by the shapes of the curves; and the total potential less the probe potential at the edge of the sheath was taken as  $V_2$ .

The increase of mobility with the potential is shown to be small, if it exists at all. The mobility indicated in each case can be calculated, assuming  $m = 1$ , by the following relation:  $k_1 = 6.4845 \times 10^{11} \times I x_2^3 / V_2^2$  cm per sec. for one volt per cm.  $I$  is in amps,  $x_2$  in cms, and  $V_2$  in volts.

III. *Variation of mobility with nature of salt sprayed.* Solutions of RbCl and CsCl were sprayed into the flame, and their mobilities compared with those obtained for KCl. The results are shown in Table III.

TABLE III. *Sheath thickness and currents for flames sprayed with CsCl and RbCl*

Salt	$x_2$ cm	$I \times 10^6$ amps	$V_2$ volts	$10^{12} \times Ix_2^3/V_2^2$
CsCl	0.22	10.0	138	5.59
RbCl	0.265	5.2	139	5.08

The mean value for all the trials for KCl is about  $Ix_2^3/V_2^2 = 5.4$ ; so there seems no reason to doubt that the positive flame-ions of all these salts have the same mobility.

The value of the calculated mobility depends on  $m$  thus:  $k_1 = 32\pi ix_2^3 / [(m+4)^2(m+2)V_2^2]$ . Taking the mean value of  $Ix_2^3/V_2^2$  equal to 5.4,  $k_1$  was calculated for several values of  $m$ . The results are shown in Table IV.

TABLE IV. *Mobility of positive ions of Rb, Cs and K in flames*

$m$	$(m+4)^2(m+2)$	$k_1$ (cm/sec per volt/cm)
0.	32	8.2
1	75	3.5
2	144	1.8
3	245	1.07

It is seen that by taking  $m$  equal to 2 or 3, the calculated value of  $k_1$  comes into better agreement with  $k_1 = 1$ . For either of these values of  $m$ ,  $q(1-x/x_1)^m = q - an_1n_2$  is continuous at  $x = x_1$ .

The mean value of the mobility of the positive ions of Rb, Cs, and K salts in flames is about 1.8 cms per sec. for one volt per cm, calculated for  $m = 2$ . It is believed that the value of  $m$  is greater than one, for then troublesome discontinuities disappear, and the calculated mobility is in reasonably good agreement with the results of other investigators.

There is some indication that the mobility increases as the electric intensity increases, but the experiments give no proof of a change of mobility with the concentration of the salt.

I wish to thank Dr. H. A. Wilson for suggesting this problem, and Dr. C. W. Heaps for valuable criticisms and suggestions.

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HOUSTON, TEXAS,  
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