THE HALL EFFECT IN FLAMES.

By Harold A. Wilson.

THE Hall effect in a Bunsen flame was investigated by E. Marx[1] in 1900. A small flat flame between the poles of a large electromagnet was used and a current was passed through this flame in a vertical direction between two horizontal electrodes of platinum wire gauze. The vertical potential gradient was measured by means of two wires one above the other which were connected to a quadrant electrometer. The horizontal potential gradient of the Hall effect was found with a second pair of wires also connected to a quadrant electrometer. If X denotes the horizontal gradient, Y the vertical gradient and H the strength of the magnetic field then Marx found that X/HY had the following values in flames containing the vapors of different alkali metal salts.

Metal.	$-X/HY$.
Cæsium	1.72×10^{-6}
Rubidium	2.70 "
Potassium	3.72 "
Sodium	5.06 "
Lithium	7.86 "
Flame free from salt	10.18 "

The above values of X/HY for salts are those found when strong solutions of the salts were sprayed into the flame. With weaker solutions the values found were more nearly equal to that in the flame free from salt. The conductivity of a flame is increased by the presence in it of an alkali metal salt and the increase is greater the higher the atomic weight of the metal. It appears therefore that in Marx's experiments the Hall effect observed diminished as the conductivity of the flame increased.

If k_1 and k_2 denote the velocities of the positive and negative ions, respectively, due to one volt per cm. then according to the theory of the Hall effect in an ionized gas we have approximately

$$\frac{X}{HY} \times 10^8 = k_1 - k_2,$$

where H is expressed in electromagnetic units. In a Bunsen flame the

[1] Ann. der Physik, Band 2, 1900.

velocity of the negative ions is large compared with the velocity of the positive ions so that k_1 can be neglected and we have $k_2 = -X/HY \times 10^8$. Now the negative ions in a Bunsen flame are generally believed to be free electrons so that we should expect k_2 to be independent of the amount and nature of the salt present in the flame.

Marx's results therefore do not agree with the theory that the negative ions are electrons. A possible explanation of this discrepancy was suggested by the writer.[1] In Marx's experiments the horizontal electrodes were about 3 cm. apart and the distance between the two wires used to measure the horizontal gradient X was also about 3 cm. The horizontal electrodes of course are equipotential surfaces so that they must tend to prevent the formation of a horizontal potential gradient in the space between them. This effect we should expect to be greater the greater the conductivity of the flame. It seems possible therefore that the diminution of the Hall effect with increasing conductivity, observed by Marx, may be a spurious effect produced by the nearness of the horizontal electrodes to the place where the Hall effect was measured.

The experiments described below were undertaken with the object of measuring the Hall effect in a Bunsen flame containing different alkali salts under conditions which would permit the full value of the Hall effect gradient to be observed. The results obtained show that the Hall effect is nearly independent of the conductivity of the flame and of the current passing through it in agreement with the theory.

Fig. 1 shows the burner and electrodes used. The burner consisted of a row of seven fused quartz tubes cemented into a brass tube AB. A mixture of gasoline gas, air and spray of a salt solution entered at A and was burnt from the quartz tubes giving a row of seven small Bunsen flames which were in contact as shown. The whole formed a flame about 12 cm. high, 12 cm. wide and 1.5 cm. thick. This flame was placed between the flat poles of a Weiss electromagnet which were 10 cm. in diameter and 3.5 cm. apart. The circle MM' indicates the position of one of the poles. A current could be passed horizontally across the flame between two platinum electrodes E and E' which were kept bright red hot by the flame. These electrodes were about 9 cm. apart and consisted of circular disks 1.5 cm. in diameter supported by stout platinum wires. The Hall effect was measured by means of two platinum wires at H and H' perpendicular to the plane of the paper in Fig. 1. These wires were about 0.2 mm. in diameter and passed right through the flame; they were well insulated and connected to an insulated quadrant

[1] Electrical Properties of Flames, page 114.

electrometer. Fig. 2 shows the arrangement used to support the wires H and H'. MM' and NN' represent the poles of the magnet and the flame is shown between them. The wires H and H' were supported by glass tubes GG and $G'G'$. These tubes passed through two ebonite plugs

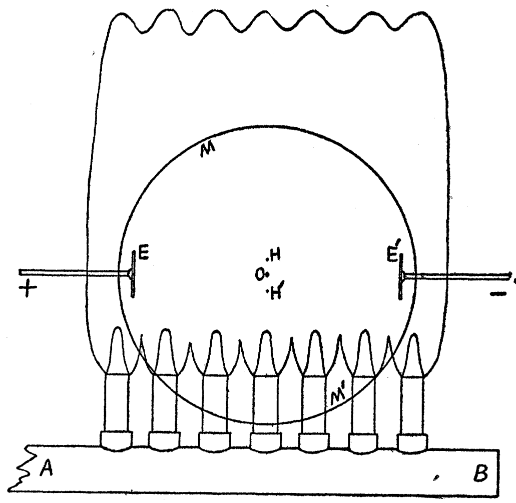

Fig. 1.

P and P' fitted tightly into the opposite ends of a brass tube AB which could be turned round in the hole bored in the pole MM'. C is a graduated circle over which a vernier V reading to $1/10°$ turned. This vernier was carried by the tube AB. In this way the wires H and H' could be rotated about an axis at O (Fig. 1) and the angle turned through measured.

If a current is passed through the flame between the electrodes E

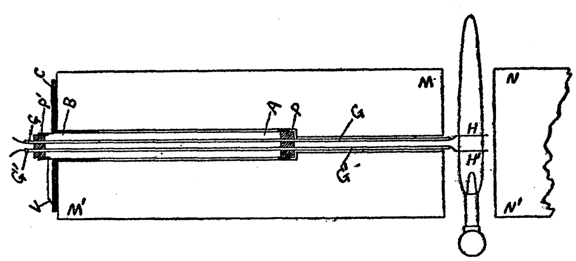

Fig. 2.

and E' the equipotential surfaces, near the line EE', in the absence of a magnetic field are approximately vertical planes perpendicular to the faces of the poles of the magnet. If the wires H and H' are turned round till the electrometer shows that they are at the same potential then they both lie on one of the equipotential surfaces. If now the magnet is excited the equipotential planes are rotated about an axis parallel to the magnetic field and the electrometer is deflected. By turning the wires H and H' round till they are again at the same potential the angle through which the magnetic field rotates the equipotential planes can be determined. If this angle is denoted by θ we have

$$\tan\theta = \frac{X}{Y}.$$

By this method the ratio of the horizontal and vertical potential gradients is obtained from a single observation and it is not necessary to know the sensibility of the electrometer. It was found best to measure the angle of rotation of the equipotential planes first with the magnetic field in one direction and then with it in the opposite direction. The mean of the two angles was taken as a measure of the Hall effect.

Measurements were made with the wires H and H' 3 cm., 1 cm. and 0.5 cm. apart. The angles were nearly the same in each case.

The mixture of gas, air and spray was obtained by means of a Govy sprayer worked by air at a constant pressure of 14.4 cm. of mercury above that of the atmosphere. The gas supply was kept at a constant pressure of 2 cm. of water.

In spite of the careful regulation of the gas and air supplies the flame varied appreciably. This was probably due chiefly to variations in the quality of the gas. In consequence of these variations the results obtained on different days did not agree as well as those obtained nearly at the same time. The variations however were usually less than 5 per cent. The flame used was a well-oxidized flame having sharply defined inner cones on each of the quartz tubes.

When a current is passed horizontally through a Bunsen flame between hot platinum electrodes there is a large drop of potential close to the negative electrode and an uniform potential gradient in the space between the electrodes. This uniform gradient is proportional to the current. If a salt like potassium carbonate is put on the negative electrode the drop of potential there is greatly diminished and the uniform gradient correspondingly increased. The ratio of the uniform gradient to the current remains unchanged provided the potassium carbonate vapor does not get into the flame except near the negative electrode. In making measurements of the Hall effect by the method described above it is difficult to get accurate results unless the potential gradient in the flame is considerable. In all the experiments of which the results are given below potassium carbonate was put on the negative electrode but care was taken that its vapor did not get near to the Hall effect electrodes.

It was found that the potassium carbonate did not change the value of the Hall effect in the flame but it made it much easier to measure.

The sensibility of the quadrant electrometer used was about 500 scale divisions per volt. A rotation of the electrodes H and H' of 1/10 of a degree usually produced an electrometer deflection of several cm. To measure the Hall effect the electrodes H and H' were turned so that the electrometer deflection was zero. A current was then passed through the electromagnet which usually caused the electrometer to be deflected through a large angle of 45° or more. This deflection was reduced to zero by rotating the electrodes. The magnet current was then reversed and the deflection again reduced to zero. The horizontal potential gradient in the flame was varied from about 5 volts per cm. to 30 volts per cm. In most of the experiments it was about 20 volts per cm.

It was found that the Hall effect angle was nearly independent of the current through the flame and therefore of the horizontal potential gradient.

The following results were obtained with the flame containing rubidium chloride and a magnetic field of strength 4,850. The magnetic field was found with a bismuth resistance.

Current in Milliamperes.	Hall Effect Angle.
8	6.6°
12	6.9
16	6.9

The following results were obtained at another time with the flame free from salt and a field 4,850.

Current. 1 = 10^{-4} ampere.	Angle.
2.3	6.9°
3.3	6.6
6.0	7.1
6.9	6.9
10.8	6.3

The following table gives the results obtained with different salt solutions and magnetic fields. Each result is the mean of several obtained with different currents passing through the flame. The distance between the Hall effect electrodes was one cm. in most cases.

It will be seen that the Hall effect angle is practically the same for the flame without salt and the flame containing different amounts of rubidium, potassium, sodium or lithium salts. The amounts of the different salts which entered the flame were in all cases sufficient to color it very strongly and to greatly increase its conductivity. When using the 10 per cent. K_2CO_3 solution the quartz tubes became rapidly clogged with solid K_2CO_3.

Solution Sprayed into Flame.	Magnetic Field Strength.	Hall Effect Angle.
Water	7,700	10.2°
Water	4,850	6.3
Water	2,250	3.0
2 per cent. LiCl	7,700	10.9
2 per cent. LiCl	4,850	7.0
2.4 per cent. Na_2CO_3	7,700	10.7
2.4 per cent. Na_2CO_3	4,850	6.9
2.4 per cent. Na_2CO_3	2,250	3.0
10 per cent. K_2CO_3	7,700	11.0
2.6 per cent. K_2CO_3	7,700	10.7
2.6 per cent. K_2CO_3	4,850	7.0
2.6 per cent. K_2CO_3	2,250	3.1
0.26 per cent. K_2CO_3	7,700	10.0
0.26 per cent. K_2CO_3	4,850	6.4
0.26 per cent. K_2CO_3	2,250	3.3
2 per cent. RbCl	7,700	10.8
2 per cent. RbCl	4,850	6.8
2 per cent. RbCl	2,250	3.4

The following are the mean values of the Hall effect angle (θ) found with the three magnetic field strengths (H) used. The values of tan θ and tan θ/H are also given.

Magnetic Field (H).	Hall Effect, Angle (θ).	Tan θ.	$\frac{\tan\theta}{H}$.
7,700	10.6°	0.1871	2.44×10^{-5}
4,850	6.7°	0.1175	2.42×10^{-5}
2,250	3.2°	0.0559	2.48×10^{-5}
Mean			2.45×10^{-5}

It appears that tan θ is nearly proportional to H. According to the theory of the Hall effect in an ionized gas in which the velocity of the negative ions (k_2) is large compared with that of the positive ions we have

$$k_2 = \frac{\tan\theta}{H} \times 10^8.$$

The results obtained therefore give $k_2 = 2{,}450$ cm. per sec. for one volt per cm.

A number of attempts[1] to measure the velocity of the negative ions in a Bunsen flame have been made by different physicists and results varying from about 1,000 cm. per sec to 20,000 cm. per sec. obtained. The great variation in the results may be partly due to differences between the flames used but such differences probably cannot account for more

[1] See Electrical Properties of Flames.

than a small fraction of the variation. The result just obtained from the Hall effect is probably as likely to be correct as any other but since the theory of the Hall effect is not above suspicion too much reliance ought not to be placed on the absolute value found. There seems no reason to doubt the correctness of the conclusion that the velocity of the negative ions is the same for all alkali metal salts in a particular flame.

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