A SOURCE OF INACCURACY ENCOUNTERED WHEN MEASURING DRIFT VELOCITIES OF ELECTRONS IN GASES BY AN ELECTRICAL SHUTTER METHOD

By R. W. Crompton,* Barbara I. H. Hall,*† and W. C. Macklin*‡

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Summary

In this paper attention is drawn to the precautions which must be adopted when the drift velocities of very slow electrons are to be measured by an electrical shutter method. While the experimental results (which for convenience were taken in hydrogen) show that quite serious errors may result at very low energies when the experimental conditions are unsuitably chosen, they also show that it is possible to reduce such errors to any required degree by appropriate choice of the parameters l and p. The form of the variation of the measured from the true values is in qualitative agreement with a formula given by R. A. Duncan when discussing diffusion in relation to measurements of this type.

I. Introduction

Increasing interest has recently been shown in the motions of electrons in diatomic gases when the electrons have energy less than $0 \cdot 25$ eV. When diffusion methods are used in these studies, it is necessary to measure the velocity of drift W of the electrons in a constant and uniform electric field Z in a gas at pressure p. The most satisfactory method of measuring drift velocities has proved to be the electrical shutter method developed by Bradbury and Nielsen (1936), but the range of energy investigated by them barely overlaps the region in question. Consequently, experiments of this type have been made in these laboratories to extend the range to lower energies, and in the course of the investigation a source of inaccuracy has been encountered which does not appear to have been previously recorded.

It is well known that the drift velocity is a function of the ratio Z/p only and not of Z or p separately. This dependence serves as a useful experimental cross-check since the same functional dependence of W on Z/p should be obtained regardless of the gas pressure employed. However, when measurements of drift velocity were made in hydrogen with an apparatus of similar dimensions to that used by Bradbury and Nielsen in their experiments with this gas it was found that the experimentally measured values W_E did not always depend only on Z/p. While the simple functional dependence reported by Bradbury and Nielsen was confirmed over a large part of the range investigated by them, for low values of the electron energy a considerable dependence of W_E upon the pressure was

* Department of Physics, University of Adelaide.

† Present address: University College, London.

‡ Present address: Division of Radiophysics, C.S.I.R.O., Chippendale, N.S.W.

observed for a given value of the energy. As described later, when apparatuses of different dimensions were used the effect became more pronounced as the distance between the shutters decreased, while for an apparatus of given length the experimental values approached asymptotically a constant value for sufficiently high gas pressures.

II. Apparatus

The principle of the electrical shutter apparatus developed by Bradbury and Nielsen is outlined below. Electrons produced by the action of ultraviolet light move under the influence of a uniform electric field parallel to the axis of the apparatus towards a grid consisting of a number of closely spaced, parallel wires insulated from each other and lying in a plane perpendicular to the field. Alternate wires of the grid are connected together and the application of a potential difference of a few volts between the two sets of wires produces cross fields which prevent the passage of electrons through the grid. If an alternating potential is applied, groups of electrons are produced, the centres of mass of which are equally spaced and move with uniform velocity to a second shutter identical with the first and a distance l from it.

An alternating potential difference is applied to the wires of the second shutter of the same frequency and phase as that applied to the first shutter and adjustment of the frequency f is made until maximum electron current is passed by the second shutter. If this maximum is considered as indicating that the centre of a group produced by the first shutter traverses the distance l in the time taken for a reversal in phase of the potential difference the following formula results

$$W_E = 2fl. \qquad (1)$$

In the present set of experiments an apparatus (Fig. 1) similar to that described by Bradbury and Nielsen was constructed but with the distance between the planes of the shutters equal to 3·00 cm instead of 5·93 cm. As it was originally intended to use the apparatus for measuring drift velocities in air, in which attachments are known to occur, the shorter length was chosen to reduce the background current caused by negative ions. Electrons were produced from a filament of 0·0016 in. diameter platinum wire and accelerated towards a region in which the electric field was the same as that between the shutters, thus allowing them to reach a steady state before the measurement of the time of flight. A shield surrounded this preliminary region to prevent the diffusion to the receiving electrode of those electrons not passing through the shutters.

The oscillator used to supply the alternating voltage to the shutters was checked for accuracy at several frequencies and was found to be stable and accurate to better than 2 per cent. Since the output of the oscillator was sensibly constant for quite considerable alterations to the frequency, the experimental procedure for measuring each value of drift velocity was simply to vary the oscillator frequency, keeping the values of electric field and gas pressure constant. This procedure, while being more convenient than that of Bradbury and Nielson, is also free from the additional complication of changes in the average electron current arriving at the second shutter caused by changes in the electric field.

A possible source of inaccuracy when using an apparatus of this type is non-uniformity in the electric field in the region between the shutters caused by the alternating electric field between the wires comprising each shutter. In the

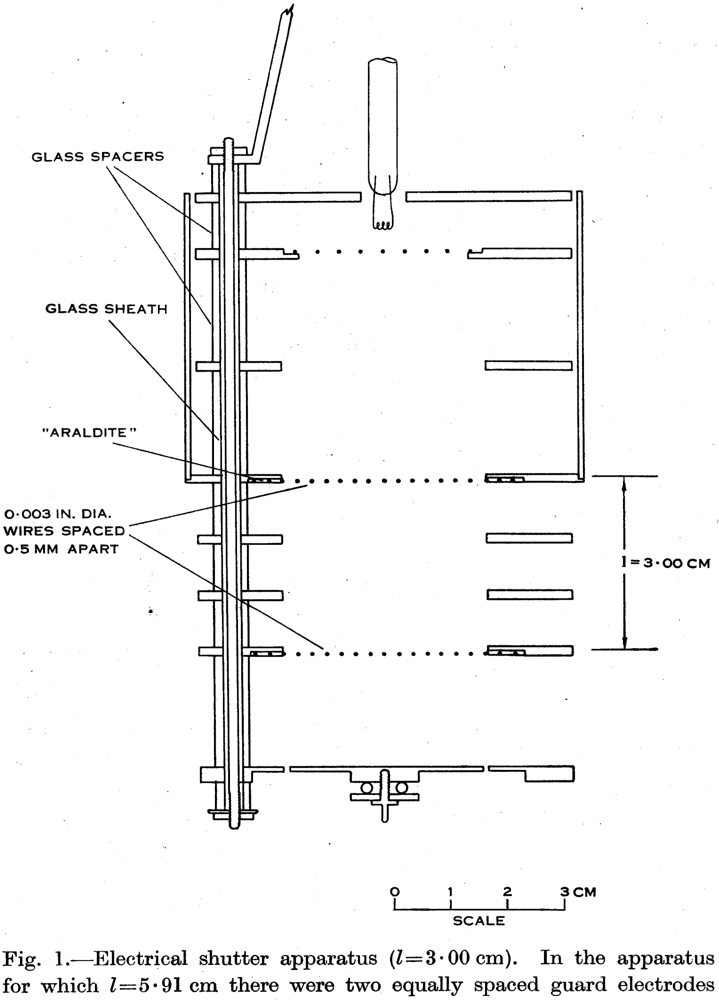

Fig. 1.—Electrical shutter apparatus ($l=3\cdot00$ cm). In the apparatus for which $l=5\cdot91$ cm there were two equally spaced guard electrodes between the shutters, and in that for which $l=10\cdot0$ cm there were four equally spaced electrodes.

present case this proved to be negligible, since large variations in the alternating voltage applied to the shutters produced no detectable change in the measured value of the drift velocity.

As shown by Table 1, the results in hydrogen obtained with an apparatus of these dimensions differ markedly from those given by Bradbury and Nielsen for pressures of the order of 10 mm Hg and approach their values asymptotically only when comparatively high pressures are used. Since no reference to such

TABLE 1

VALUES OF $W_E \times 10^{-5}$ CM/SEC MEASURED IN HYDROGEN FOR A RANGE OF VALUES OF Z/p AND p AND FOR THREE VALUES OF l

For a given Z/p and p the entries correspond to $l=3\cdot00$, $5\cdot91$, and $10\cdot0$ cm reading from top to bottom

Z/p \ p	4	5	6	7	8	9	10	12	15	20	25	30	40	50	60	70	80	90	100	120	150	$W_B \times 10^{-5}$
0·05														1·89	2·20	2·08	1·99 1·90	1·95	1·92 1·88	1·90	1·90	2·0
0·1												3·60	3·43 3·20	3·31 3·25	3·19	3·42 3·13	3·07 3·20	3·30 3·07	3·30 3·09 3·12	3·08	3·10	3·20
0·2								5·44	5·32	5·20	5·08	4·96		5·22 4·85 4·80	4·80	4·92	4·80	4·86	4·86			4·80
0·3							6·58	6·39	6·15	6·20 5·80	6·15	6·30 5·96	5·84	6·30 5·90 5·90		5·82		5·94	5·88			5·9
0·4							7·2	7·0	6·9	6·85 6·7	6·9	7·14 6·74		7·02		6·72		6·78				6·6
0·5		8·5	8·3	8·3	8·3	8·1	10·2 7·9	9·9 7·8	7·7	9·0 7·6 7·4		7·8	7·8	7·65	7·68	7·68						7·3
1·0	14·4 11·1	12·9 11·0	12·3 10·6	12·1 10·4	12·0 10·2	10·0	12·0 10·1	11·1 10·2		10·3		10·2										9·9

an effect could be found in the literature, it was decided to increase the distance between the shutters to a value (5·91 cm) close to that used by Bradbury and Nielsen. Subsequently the distance was increased to 10·0 cm to investigate the effect more fully.

III. Results and Discussion

Table 1 shows the results obtained in hydrogen using formula (**1**) when the distance between the shutters is 3·00, 5·91, and 10·0 cm for pressures in the range 4–150 mm Hg. The values W_B obtained by Bradbury and Nielson are given for comparison in the last column of the table. It will be noted that the agreement is generally good. It should be emphasized, however, that no claim is made that the present results are more accurate than those of Bradbury

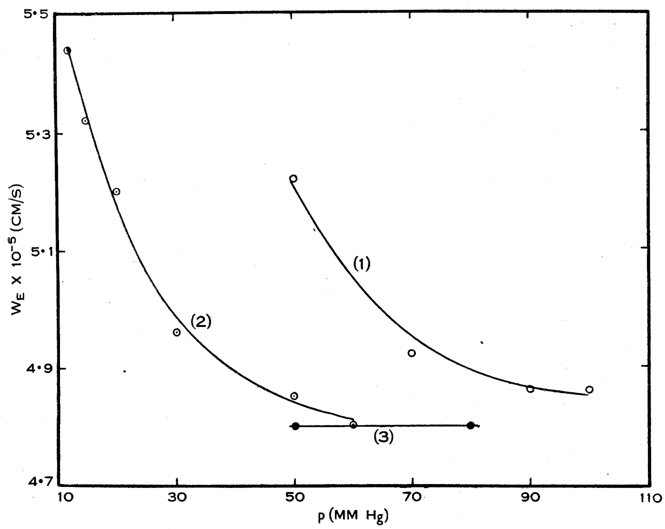

Fig. 2.—Results taken in hydrogen showing the variation of W_E with pressure and distance between shutters for $Z/p=0\cdot 2$ V cm^{-1} (mm Hg)$^{-1}$; (1) $l=3\cdot 00$ cm, (2) $l=5\cdot 91$ cm, (3) $l=10\cdot 0$ cm.

and Nielsen. The dependence of W_E on p and l for a given Z/p having been observed in both hydrogen and nitrogen, the sole aim of the experiments described here was to make a systematic study of the dependence, firstly to ascertain the cause and secondly to assist in designing experiments capable of determining accurately drift velocities at very low values of Z/p. Hydrogen was chosen simply for the ease with which samples of consistent purity may be prepared. Nevertheless, since the gas was admitted through a palladium thimble into a system evacuated to a pressure of less than 10^{-3} mm Hg, it is considered that the results are reliable to the limit of accuracy of the oscillator.

Figure 2 shows the variations of the measured values with pressure for the three values of l for a typical value of $Z/p=0\cdot 2$ V cm^{-1} (mm Hg)$^{-1}$. On these graphs the scatter of the points from the corresponding curves of best fit is considerably less than the ± 2 per cent. quoted for the accuracy of the oscillator, since for any given curve the frequency of the oscillator had only to be varied over a small portion of the total frequency range. Experimental difficulties, as, for example, lack of current falling on the receiving electrode, prevented measurements being taken at the same pressures for each length. Thus it was found impossible to extend to lower pressures the measurements taken with $l=10\cdot0$ cm.

Both the graphs and the table demonstrate that, for a given value of Z/p,

(*a*) when l is fixed, the measured values of drift velocity W_E are a function of the pressure, decreasing to a limiting value W as p increases, and

(*b*) for a given pressure, as l increases the values W_E decrease and approach asymptotically a value W.

Moreover, if both l and p are held constant, the discrepancy between W_E and W decreases as Z/p increases. W may justifiably be taken as the correct value of the drift velocity and it will be seen that there is good agreement between these values and those published by Bradbury and Nielsen. It will be seen from the table that, when $l=5\cdot91$, a length almost identical with that used by them, and the pressure exceeds 10 mm Hg the effect is barely noticeable.

The fact that, when the effect is observable, the measured values are always greater than the true values points to the discrepancy having its origin in the diffusion of the electron groups in transit between the shutters. Formula (**1**) is derived on the assumption that diffusion may be neglected, that is, on the assumption that the experimentally measured quantity is the time interval which elapses between the generation of a given group by the first shutter and the transit of the centre of mass of the group through the second shutter. In a recent paper R. A. Duncan (1957), examining theoretically the problem experimentally investigated here, considers the *total* flow of current across a plane situated at the second shutter. As is well known, the sum of the contributions to the current from diffusion and drift is proportional to

$$(K\partial n/\partial z+nW),$$

where n is the electron concentration and the plane is considered perpendicular to the z-axis. Duncan shows that under certain conditions the time at which the flow of current is a maximum occurs significantly earlier than the transit time of the centre of the group across the plane. By reference to the experimental procedure outlined in Section II it may be seen that the frequency which is used in calculating W_E from formula (**1**) is in fact that for which there is a complete reversal of phase of the voltage applied to the shutters when the current flow through the second shutter is a maximum. An approximate formula resulting from the more correct treatment for the case when the discrepancy between true and measured values is small is

$$W_E=W(1+2K/lW), \qquad (\mathbf{2})$$

where K is the coefficient of diffusion. The formula predicts that, as might be expected, the measured values should approach the true values as the ratio K/W decreases, that is, as Z/p or p increases (Crompton and Sutton 1952). Moreover, an increase in the distance l between the planes of the shutters should give rise to smaller discrepancies between true and measured values for a given set of experimental conditions.

The results in Table 1 confirm qualitatively the predictions of this formula but unfortunately, when a quantitative test is made with the experimental data, good agreement is not obtained. Two possible explanations of this enhanced discrepancy are

(*a*) as suggested by Duncan, the proximity of the receiving electrode to the second shutter may result in an increased electron concentration gradient in this region, and

(*b*) the removal of electrons from the groups by the shutters and the guard electrodes promoting more pronounced onward diffusion.

Despite the poor quantitative agreement between theory and experiment, both establish the fact that, unless appropriate precautions are taken, serious errors may result when determining drift velocities by this method. The experimental results show that reliance should be placed on the measured values only after a sufficiently extensive range of pressure has been investigated to ensure that the asymptotic value has been closely approached.

IV. Acknowledgments

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