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The Ratio D_L/μ for Electrons in Helium at 293 K

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Abstract

The Bradbury–Nielsen method has been used to measure the ratio of the longitudinal diffusion coefficient D_L to the electron mobility μ in helium at 293 K over the E/N range 0·024–0·607 Td. The absolute error is estimated to be less than $\pm 3\%$. The present results agree with those of Wagner *et al.* (1967), to within the combined experimental errors over the common range of E/N values, and are also compatible with the values predicted by Lowke and Parker (1969) from calculations based on the momentum transfer cross section of Crompton *et al.* (1967).

Introduction

Following the experimental work of Wagner *et al.* (1967) which demonstrated that the diffusion of an electron swarm in a uniform electric field is anisotropic, Parker and Lowke (1969) and Skullerud (1969) derived a formula for the ratio D_L/μ (where D_L is the longitudinal diffusion coefficient and μ the electron mobility). The reliability of this formula can only be established by comparing experimental values of D_L/μ with those calculated from cross sections whose accuracy has been well established. The most accurately known momentum transfer cross section is that for electrons in helium (Bederson and Kieffer 1972) but the comparison of experimental and predicted values of D_L/μ for this gas has been hampered by the lack of sufficiently accurate experimental data. The only data available are those of Wagner *et al.* (1967), which have a scatter of up to 10% and do not extend below $E/N \approx 0\cdot3$ Td, and those of Crompton and Elford (cited by Lowke and Parker 1969), which exhibit a scatter of as large as 20%. The purpose of the present work was to obtain values of D_L/μ with considerably higher precision than the data previously available in order to make a much more rigorous test both of the formula for D_L/μ and the experimental method.

Experimental Method

The experimental values of D_L/μ were obtained using the Bradbury–Nielsen time-of-flight technique. This method has been used extensively to measure electron drift velocities and is described in detail by Elford (1972). The application of the technique to determine values of D_L/μ has been discussed by Milloy (1973). The method used by Milloy is based on the expression derived by Huxley (1972) for the number density n of an electron swarm as a function of the time t and the distance from the plane of the first shutter grid. The electrons are assumed to be all admitted to the drift chamber at

$t = 0$. The boundary conditions assumed are $n = 0$ at both the shutter grids which define the drift chamber.

The flux of charged particles ϕ transmitted by the second grid to the collector electrode is given by

$$\phi = A\,t^{-\frac{1}{2}}(h^2/4D_L t - 2)\exp\{-(h - Wt)^2/4D_L t\}, \tag{1}$$

where A is a constant, h is the drift chamber length (10·000 cm in the present work) and W is the drift velocity. Under the present experimental conditions $h^2/4D_L t \gg 2$ and, assuming that the factor $t^{-3/2}$ has a negligible effect on the current–time distribution, the flux to the collector may be written

$$\phi = A'\exp\{-(h - Wt)^2/4D_L t\}. \tag{2}$$

Lowke (1962) has shown that the resolving power $\mathscr{R}$ defined by the time t_0 at which the current is a maximum divided by the difference between the times t' and t'' at which the current has half the maximum value is given by

$$\mathscr{R} = \frac{t_0}{t'' - t'} = \frac{1}{4}\left(\frac{V}{(D_L/\mu)\ln 2}\right)^{\frac{1}{2}},$$

where $V = Eh$ is the potential difference across the drift chamber. Thus

$$D_L/\mu = V/16\mathscr{R}^2 \ln 2. \tag{3}$$

The effect of neglecting the factor $t^{-3/2}$ from equation (2) was investigated in the same manner as that employed by Milloy (1973) and shown to result in a negligible error in $\mathscr{R}$ for all the experimental conditions used in this work. In deriving equation (3) it is assumed that the open time of the shutter is negligible compared with the difference $t'' - t'$ (for cases where this assumption has not been made, see Barnes 1967; Orient 1971). The validity of the assumption of a negligibly wide source pulse was checked by measuring the resolving power as a function of the open time. Since the open time decreases as both the shutter signal amplitude and the peak order number increase, the condition corresponding to a negligibly wide source pulse was determined from a plot of the resolving power versus shutter signal amplitude for peaks of increasing order. The value of $\mathscr{R}$ appropriate to the relation (3) was taken as that value of $\mathscr{R}$ which was independent of further increase in either the signal amplitude or peak order number. A typical plot of $\mathscr{R}$ versus shutter signal amplitude is shown in Fig. 1. Each point on this plot is the average of 10 measurements of $\mathscr{R}$. Because it was necessary to use very small open times there was a very large attenuation in electron current caused by the operation of the first shutter grid and, as a consequence, relatively large initial electron currents had to be used to obtain sufficient current for accurate measurement. The electrons were produced by volume ionization of the gas by α-particles emitted from an americium-241 foil, and to obtain adequate currents from this source it was necessary to use gas pressures $p \geqslant 200$ torr. The total range of pressures used was 200–500 torr. Checks were made to ensure that the data were not subject to space charge effects.

The apparatus employed was that described by Crompton *et al.* (1970). The helium used was Matheson Research Grade and was not further purified. The data were independent of the time the helium was held in the experimental tube, indicating that the measurements were not subject to errors arising from impurities introduced by outgassing.

The lower limit of the E/N range was set by insufficient current for accurate measurement and the upper limit by the onset of ionization between the grid wires of the shutter grids. At the very large signal amplitudes required to produce sufficiently narrow pulses at high E/N values, the electrons obtained enough energy from the electric field between successive grid wires to ionize the helium gas. This caused the observed current peaks to become broadened and to give rise to a large electron current background. This effect occurred at values of the shutter signal amplitude which were still insufficiently large to attain a constant value of the resolving power even though peaks of high order (as great as seven) were used. It was not possible to use peaks of higher order than seven due to insufficient electron current.

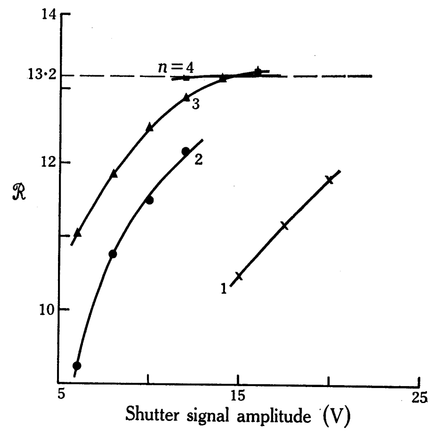

Fig. 1. Resolving power $\mathcal{R}$ as a function of the amplitude (peak to peak) of the sinusoidal potential applied to the shutter grids for successive maxima (n) in the electron current-frequency spectrum. Each point on the plot is an average of 10 measurements of $\mathcal{R}$. The experimental conditions were $E/N = 0 \cdot 152$ Td, $p_{293} = 201$ torr.

Results and Discussion

The present values of D_L/μ are shown in Table 1 as a function of E/N and $p_{293 \cdot 2}$. It can be seen that the values are independent of pressure to within the scatter of the data, which is almost entirely due to the instability and noise in the electron current measurement. In determining the 'best estimate' values in Table 1, the data were weighted in favour of the values taken at the highest gas pressures since the available electron current was greatest at these values. The best estimate values are considered to have an absolute error of less than $\pm 3\%$ and when plotted (Fig. 2) exhibit a scatter about a curve of best fit of less than $\pm 2\%$. The present data agree with those of Wagner *et al.* (1967) to within the combined experimental error over the limited common range of E/N values.

Values of D_L/μ as a function of E/N were calculated by Lowke and Parker (1969) assuming the energy-dependent momentum transfer cross section of Crompton *et al.* (1967), and are shown by the dashed curve in Fig. 2. The error in the calculated curve is estimated by Lowke and Parker to be $\pm 2\%$. It can be seen that the present experimental values agree with the predicted curve to within the combined errors of the experimental and calculated values over the full E/N range 0·024–0·607 Td. However, on close examination it appears that within this E/N range the predicted and experimental curves diverge, the difference increasing as E/N increases. At values of $E/N > 0\cdot6$ Td, where only the data of Wagner *et al.* are available, the discrepancy between the predicted curve and the experimental curve of best fit is as large as 10%.

Table 1. Experimental values of D_L/μ as a function of E/N and $p_{293\cdot2}$ for electrons in helium

E/N (Td)	D_L/μ (mV) $p_{293\cdot2}$ = 510	302	Best estimate	E/N (Td)	D_L/μ (mV) 510	302	201 torr	Best estimate
0·0243	26·9		26·9	0·1517	50·1	49·8	51·5	50·1
0·0303	27·2		27·2	0·1820	56·5		56·3	56·5
0·0364	28·7		28·7	0·2124	63·6		62·3	63·6
0·0455	29·3		29·3	0·243	68·9	69·6	69·4	68·9
0·0546	30·6		30·6	0·273	73·3		74·5	73·3
0·0607	32·4	33·0	32·4	0·303	80·7	79·7	81·7	80·7
0·0759	35·9		35·9	0·455		111	111	111
0·0910	38·0		38·0	0·607			137	137
0·1214	44·6		44·6					

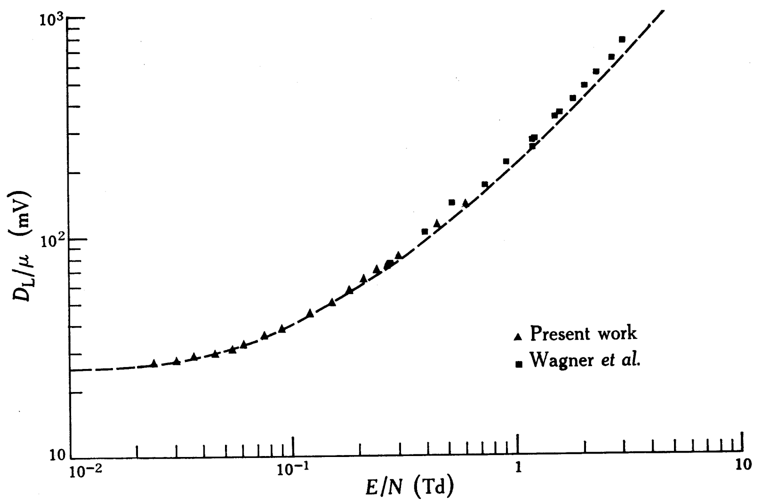

Fig. 2. Comparison of the present experimental values of D_L/μ as a function of E/N and also those of Wagner *et al.* (1967) with the results (dashed curve) predicted by Lowke and Parker (1969) using the momentum transfer cross section of Crompton *et al.* (1967).

Conclusions

The agreement between the present experimental values of D_L/μ and those predicted from the Parker and Lowke (1969) formula using the momentum transfer cross section of Crompton *et al.* (1967) has been shown to be satisfactory, thus confirming the accuracy of both the experimental method and the D_L/μ formula for values of $E/N < 0\cdot6$ Td. However, it would appear that there is a significant discrepancy at values of $E/N > 0\cdot6$ Td. This disagreement was noted by Lowke and Parker (1969), and more accurate measurements are desirable at $E/N > 0\cdot6$ Td to determine whether a further extension of the theory of longitudinal diffusion is necessary.

Acknowledgments

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