

## **Drift Velocity of Electrons in Nitrogen-Argon Mixtures**

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### *Abstract*

Electron-drift velocities have been measured in mixtures of 0.1%, 1% and 5% nitrogen in argon at 293 K. A modification of the drift-tube system, which provides semi-automatic control and data collection, is described. Agreement with some previous work is very good. The uncertainty of the present measurements is estimated to be less than 1%.

### **1. Introduction**

Electron-drift velocities have been measured in mixtures of nitrogen and argon at 293 K. The ultimate aim of this work is to check the absolute magnitude of the vibrational excitation cross sections in nitrogen determined in previous experiments (Schulz 1964; Kieffer 1973) by comparing calculated and measured transport coefficients in these mixtures and in pure nitrogen. Such a program calls for a large number of measurements with the aim of producing a considerable volume of drift-velocity data having the best obtainable accuracy. For this reason a control and data handling system has been developed and installed on a drift tube in order to remove the tedium associated with the collection of such a mass of data. The design of the system is such that it does not degrade the intrinsic accuracy of techniques which have been developed previously (Elford 1971).

This paper presents the experimental data for mixtures of 0.1%, 1% and 5% nitrogen in argon. The data have an estimated experimental uncertainty of less than 1%. An analysis of the data will be presented in a further publication.

### **2. Experimental Details**

The basic drift-velocity apparatus used for the present measurements has been described in detail previously (Crompton *et al.* 1968) so that no description need be given here. Modifications were made to allow most of the associated electronics to be interfaced to a microcomputer in order to collect the data automatically.

The system is illustrated schematically in Fig. 1. The microprocessor mainframe uses a standard S-100 bus mother board with an 8080 microprocessor CPU card. It is fitted with 48 K of RAM, a disc drive controller board capable of handling four drives, and two I/O boards with a total capacity of  $18 \times 8$  bit programmable I/O ports and two serial ports configured for RS232 operation. The disc drive unit

is a single 8 in floppy unit and the digital plotter has been interfaced via three standard I/O ports so that all functions are under software control. The I/O ports use 8255 PPIA chips which have the advantage that all data lines are latched. A video display unit (VDU) and a hard copy terminal are attached to the two RS232 lines. The frequency synthesizer, which provides the sinusoidal gating signal to both shutters via the amplifiers, is interfaced via six standard ports (actually a total of 45 lines). Both the amplitude and frequency of the gating signal are under software control. The power supply, which provides the main drift field in the tube, has been modified so that its output voltage is programmable via a 16 bit data word (two standard ports) from the computer. This gives adequate resolution of the required voltages and an accuracy of better than 0.01%. The transmitted current is measured with a digital electrometer which provides a BCD output signal to the computer (three standard ports).

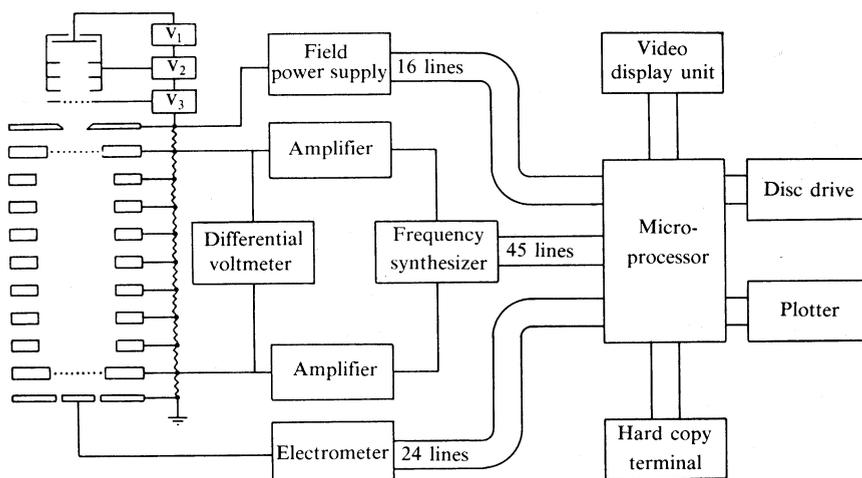


Fig. 1. Schematic diagram of the drift tube and data collection system.

With this configuration the computer has the capability of controlling the electric field strength  $E$  and the amplitude and frequency of the sinusoidal voltage applied to the shutters, and of recording the current transmitted down the tube. All data may be stored on disc and plotted on the plotter.

Two basic modes of operation are employed. In the first mode a sample of gas is let into the tube at a known pressure and temperature corresponding to a given gas number density  $N$ . The computer then records an arrival-time spectrum at a given value of  $E/N$ . The program instructs the computer to apply a sine wave of the correct amplitude and frequency to the shutters, wait a suitable time for the electrometer reading to stabilize, then record the current, increment the frequency, wait and record the current etc. The software includes provision to vary the waiting time, and also to sample the transmitted current at a given frequency a number of times and average these samples in order to reduce the noise level on the signal. The output is stored on disc and plotted. An example of an arrival-time spectrum determined in this way is shown in Fig. 2 which is a direct reproduction of the original plot produced by the computer. This mode of operation is very useful in

the initial stages of setting up an experimental run in order to ascertain that there are no unforeseen problems in either the apparatus or the data-collection system.

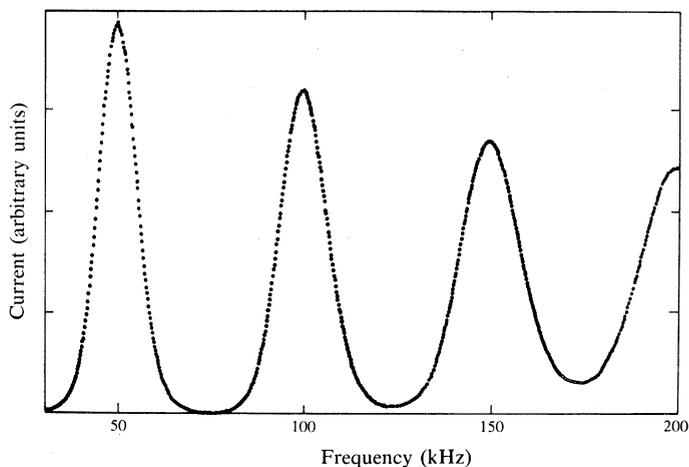


Fig. 2. Direct copy of an arrival-time spectrum recorded by the computer.

In the second mode of operation, a sample of gas is again let into the tube and the pressure and temperature entered into the computer via the keyboard of the VDU. This time the program calls for only the peak regions in the arrival-time spectrum to be recorded (the number of peaks to be scanned being an input parameter), but for a range of standard values of  $E/N$ . The computer uses the input information of pressure, temperature and drift length to calculate the main drift-field power-supply voltage appropriate to the first value of  $E/N$  and outputs these data in digital form to the power supply. It then records frequency versus current in the region of the first peak in the arrival-time spectrum, calculates the frequency at the maximum of the peak and thus the drift velocity, repeats the process at the second, third etc. peaks and then sets up the next standard value of  $E/N$  and repeats the whole process for all required values of  $E/N$ . Once again samples of the transmitted current are taken at some predetermined time after the frequency of the gating signal has been changed. As in the first mode of operation, the waiting time and the number of samples taken (to reduce the noise) are under program control. All the raw data and the results of the calculations are recorded on disc so that they can be accessed for reanalysis if necessary. In addition, the results for the drift velocity measured at each peak are available in real time on either the VDU or the hard copy terminal so that progress can be monitored.

The centre frequency of the peak is determined in much the same way as described by Elford (1971) for manual operation of the apparatus. During the operation described previously, data for current versus frequency are stored on the floppy disc. At the completion of each scan of a peak the computer retrieves these data and calculates the frequencies (in pairs), typically at the 40, 50, 60, 70, 80 and 90% level of maximum peak height. The pairs of frequencies are then averaged. These six average values are now further averaged and also extrapolated linearly to the 100% level (the peak maximum). A comparison of this extrapolated value with the average value gives a measure of the 'skewness' of the peak which is caused by a sloping back-

ground in the arrival-time spectrum [see Elford and Haddad (1980) for a discussion of this point]. The extrapolated value is the best estimate of the frequency corresponding to maximum transmitted current and is used to calculate the drift velocity  $v_{dr}$ . In the present work the maximum difference between the extrapolated and mean values was of the order of 0.3%.

The computer system, therefore, provides a method of recording and analysing a large amount of data without the necessity for intervention by an operator. Typical computer runs were of about 8 h duration providing data for  $v_{dr}$  at about ten values of  $E/N$  determined from the first four peaks in the arrival-time spectrum at each value.

Variations between the drift velocities determined from successive maxima were of the order of 0.1% and the results were repeatable from day to day to this level of accuracy.

Gas mixtures were made in specially constructed mixing cylinders of the type described previously (Crompton and Haddad 1983) but with a volume ratio of about 20:1. Mixtures were made using two quartz spiral manometers to measure the gas pressures, one with a full scale range of about 70 kPa and the other with a full scale range of about 1200 kPa. The combination of these two gauges enabled mixtures to be made with concentrations varying from 0.1% to 5% with an accuracy limited only by the determination of the volume ratio of the mixing cylinders. This ratio was measured using one of the quartz spiral manometers and a volume expansion technique and is estimated to be accurate to within 0.2% which is therefore the estimated accuracy of the mixture composition. Mixtures were usually made so that the cylinders (with a volume of about 12 L) contained a final pressure of about 1200 kPa. Enough gas was thus provided for many fillings of the drift tube at pressures up to 68 kPa. In order to maintain temperature stability during the mixing operation, the cylinders were immersed in a water bath. They were then removed from the bath and the gas mixed by rolling the cylinders for about 10 min. There was no evidence of incomplete mixing for any of the samples prepared in this way.

The gases used were both research grade with a specified purity of 99.999% for nitrogen and 99.9995% for argon. No further purification was necessary. The sensitivity of the measurements to the presence of impurities in the gas sample is very much less than in the case of pure argon (Robertson 1977), since in the present experiments concentrations of at least 1000 ppm of a diatomic gas (in this case nitrogen) are added to the argon.

At times mixtures were held in the apparatus for up to 200 h. There was no evidence of a change in the values of  $v_{dr}$  due to the introduction of impurities from the walls of the system into the sample.

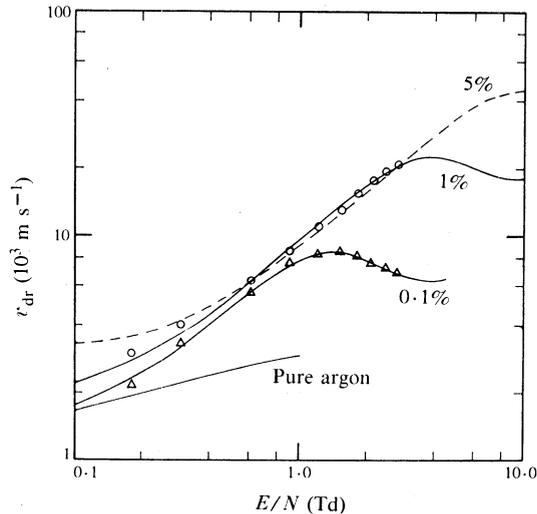
### 3. Results

The observed drift velocity  $v'_{dr}$  is related to the true drift velocity  $v_{dr}$  through the relation (Huxley and Crompton 1974)

$$v'_{dr} = v_{dr} \left( 1 + \frac{CD_{\parallel}/\mu}{V} \right),$$

where  $D_{\parallel}$  is the longitudinal diffusion coefficient,  $\mu$  the mobility,  $V$  the potential difference between the shutter planes and  $C$  a constant which depends on the mode of operation of the shutters, the ratio of the shutter open time to the transit time, and the relative sizes of the source and collecting electrode.

The validity of a relationship of this form has been demonstrated many times (Elford 1971), at least to the extent required to make the corrections to  $v'_{dr}$  necessary to obtain  $v_{dr}$ , since these are usually less than 1%. Accordingly, drift velocities were measured as a function of pressure for all mixtures, and values of  $v'_{dr}$  as a function of  $N^{-1}$  were extrapolated to  $N^{-1} = 0$ . These extrapolated values are plotted in



**Fig. 3.** Drift velocities in mixtures of 0.1%, 1% and 5% nitrogen in argon. Previous results by Nagy *et al.* (1960) are shown for 0.1% (triangles) and 1% (circles) mixtures. No data points are shown for the present work since they all fall within the thickness of the curves. Errors associated with the present data are discussed in the text. Also shown are previous results by Robertson (1977) for drift velocities in pure argon.

**Table 1.** Drift velocities of electrons in  $N_2$ -Ar mixtures at 293 K

Drift velocities ( $10^3 \text{ ms}^{-1}$ ) are tabulated for the different concentrations of nitrogen shown (1 Td =  $10^{-17} \text{ V cm}^2$ )

$E/N$ (Td)	0.1%	1%	5%	$E/N$ (Td)	0.1%	1%	5%
0.06		2.08		0.8	6.82	7.81	7.65
0.07		2.12		1.0	7.77	9.48	9.04
0.08		2.15		1.2	8.30	11.1	10.5
0.1	1.75	2.24	3.30	1.4	8.48	12.7	11.8
0.12	1.88	2.35	3.34	1.7	8.28	14.9	13.9
0.14	2.01	2.48	3.39	2.0	7.84	17.0	15.9
0.17	2.22	2.69	3.50	2.5	7.11	19.8	19.2
0.2	2.44	2.90	3.63	3.0	6.63	21.6	22.4
0.25	2.82	3.28	3.90	3.5	6.38	22.4	25.4
0.3	3.22	3.68	4.20	4.0	6.28	22.5	28.3
0.35	3.63	4.08	4.53	5.0	6.46	21.3	33.7
0.4	4.03	4.49	4.87	6.0		20.0	38.0
0.5	4.81	5.31	5.55	7.0		19.1	41.2
0.6	5.55	6.14	6.25	8.0		18.6	43.1
0.7	6.22	6.98	6.95	10.0		18.3	44.2

Fig. 3. As in earlier work, the largest correction applied to our raw data was of the order of 1% and the constant  $C$  was found to have a value of the order of 1.5. Five pressures in the range from 6.6 to 68 kPa were used for the 0.1% mixture, ten pressures between 2.7 and 68 kPa for the 1% mixture, and four pressures between 2.7 and 21 kPa for the 5% mixture.

The results of the measurements are given in Table 1 and plotted in Fig. 3 where they are compared with those by Nagy *et al.* (1960). The agreement between the two sets of results is very good. There have been several other measurements of  $v_{dr}$  in mixtures of this type (Klema and Allen 1950; Colli and Facchini 1952; English and Hanna 1953; Bortner *et al.* 1957), but in all cases the agreement with our results is not as good, there being differences ranging up to 15%. Unfortunately, with the exception of English and Hanna (1953), none of the previous authors addressed the question of accuracy which means that it is difficult to make comparisons. English and Hanna gave the accuracy of their measurements as about 10%.

#### 4. Errors

A detailed discussion of errors in measurements made by this technique has been given previously (Elford 1971). Error limits were assessed by adding the systematic and random errors. Since the total systematic error was obtained by adding the contributions arithmetically, the final assigned error may be regarded as the estimated maximum possible error. In addition to the usual errors, there is a contribution due to the error in the ratio of the component gases which is estimated to be less than 0.2%.

Taking all known sources of error into account, the values of  $v_{dr}$  in the mixtures are estimated to be accurate to within 1%.

#### 5. Conclusions

A semi-automatic control and data acquisition system has been developed for application to a Bradbury-Nielsen drift-tube system and used to obtain the large amount of data associated with a systematic survey of electron-drift velocities in nitrogen-argon mixtures. The overall system has produced data for mixtures containing 0.1%, 1% and 5% of nitrogen with an experimental uncertainty of less than 1%, and thus provided data of sufficient accuracy to enable a reliable normalization factor for the vibrational excitation cross sections of nitrogen to be obtained. This problem will be the subject of a companion paper.

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**References**

- Bortner, T. E., Hurst, G. S., and Stone, W. G. (1957). *Rev. Scient. Instrum.* **28**, 103.
- Colli, L., and Facchini, V. (1952). *Rev. Scient. Instrum.* **23**, 39.
- Crompton, R. W., Elford, M. T., and McIntosh, A. I. (1968). *Aust. J. Phys.* **21**, 43.
- Crompton, R. W., and Haddad, G. N. (1983). *Aust. J. Phys.* **36**, 15.
- Elford, M. T. (1971). In 'Case Studies in Atomic Physics', Vol. 2 (Eds E. W. McDaniel and M. R. C. McDowell), Ch. 2 (North-Holland: Amsterdam).
- Elford, M. T., and Haddad, G. N. (1980). *Aust. J. Phys.* **33**, 517.
- English, W. N., and Hanna, G. C. (1953). *Can. J. Phys.* **31**, 768.
- Huxley, L. G. H., and Crompton, R. W. (1974). 'The Diffusion and Drift of Electrons in Gases' (Wiley-Interscience: New York).
- Kieffer, L. J. (1973). A compilation of electron collision cross section data for modelling gas discharge lasers. Jila Information Center Rep. No. 13.
- Klema, E. D., and Allen, J. S. (1950). *Phys. Rev.* **77**, 661
- Nagy, T., Nagy, L., and Desi, S. (1960). *Nucl. Instrum. Methods* **8**, 327.
- Robertson, A. G. (1977). *Aust. J. Phys.* **30**, 39.
- Schulz, G. J. (1964). *Phys. Rev.* **135**, 983.

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