

Drift Velocities of Slow Electrons in Krypton, Xenon, Deuterium, Carbon Monoxide, Carbon Dioxide, Water Vapor, Nitrous Oxide, and Ammonia*

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The drift velocities of electrons in krypton, xenon, deuterium, carbon monoxide, carbon dioxide, water vapor, nitrous oxide, and ammonia have been measured for E/p values between 2.5×10^{-4} and 30 v/cm-mm Hg at temperatures between 77 and 443°K . The data were obtained from measurements of electron transit times in a double-shutter drift tube. Values of the momentum transfer cross section as a function of electron energy for electrons with energies between about 0.003 and 0.08 eV are obtained which are consistent with the measured drift velocities for thermal electrons in all the gases reported.

I. INTRODUCTION

THIS paper reports measurements of drift velocities of electrons in krypton, xenon, deuterium, carbon monoxide, carbon dioxide, water vapor, nitrous oxide, and ammonia for low E/p using an improved technique. The immediate purpose of this study was to obtain information about elastic collision cross sections from the measurements of electron drift velocities at very low E/p . The data were obtained with the drift tube described previously.^{1,2} Measurements were made by operation of the tube in the "zero bias" or "rejection" mode of grid operation as discussed in the previous paper.² In Sec. V the data obtained at low E/p are used to obtain a consistent set of momentum transfer cross sections as a function of electron energy between 0.003 and 0.08 eV.

II. METHOD

The measurements of electron drift velocity were made using the electrode structure shown schematically in Fig. 1 and described previously.² Light from the pulsed ultraviolet light source produces a photoelectric current leaving the cathode having the waveform marked I . These electrons drift from the cathode

towards the collector under the action of a uniform electric field maintained by guard rings. The currents arriving at grid No. 1 and grid No. 2 are indicated schematically by the waveforms I_1 and I_2 , respectively.

The zero-bias or rejection mode of operation of the grids is designed to reduce the perturbing effects of voltages applied to the grids by using only a pulsed voltage to collect electrons in the vicinity of the grid instead of the usual combination of dc bias and pulsed voltages.³ A pulse of voltage, delayed with respect to the light pulse, is applied between the grid wires of grid number 1 or 2. The resulting reduction in the transmission of the grids causes a change in collector current which is proportional to the density of electrons near the respective grid at the time of application of the voltage. Thus, the change in collector current as a function of the time delay between the light pulse and the application of the pulse of voltage to grid number 1 or 2 resembles I_1 or I_2 . This mode of operation has the advantage that there is no voltage between grid wires during the period between pulses. The measured values of the electron transit times, t_1 and t_2 , were found to be proportional to the respective grid distances; accordingly, the results are believed to be free of end effects.

In all gases reported in this paper, except krypton and xenon, the maximum transmission of the grids occurs at zero bias and the transmission decreases monotonically with increasing bias voltage. The pulse and bias voltages were adjusted so that the transmission of the grids were reduced to approximately 10% of the transmission obtained with no voltages or pulses applied to the grids. This gave good collector current waveforms similar to I_1 and I_2 in Fig. 1. In krypton and xenon above a certain E/p for each gas the transmission increases with bias voltage to a maximum and then decreases as the bias is increased further as was found previously to be the case for argon.² This effect is probably associated with the Ramsauer minimum in the scattering cross section but the effect has not been investigated in detail. The zero-bias method was used in krypton and xenon for E/p where the grid characteristics were normal. In the

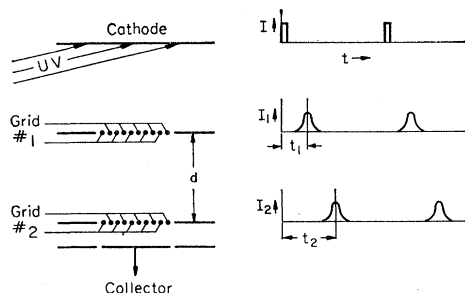


FIG. 1. Simplified schematic of drift velocity tube and waveforms showing the currents leaving the cathode and arriving at the grids. The widths of the pulses shown are not to scale.

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¹ A. V. Phelps, J. L. Pack, and L. S. Frost, Phys. Rev. **117**, 470 (1960).

² J. L. Pack and A. V. Phelps, Phys. Rev. **121**, 798 (1961).

³ For a summary of drift velocity measurements and grid designs, see L. B. Loeb, *Basic Processes of Gaseous Electronics* (University of California Press, Berkeley, California, 1955), Chaps. I and III.

abnormal region, the bias was usually set for maximum transmission and the pulse amplitude adjusted to reduce the voltage between grid wires to zero.

III. APPARATUS

The experimental tube is the same as described in the previous paper² except that drift distances of 2 and 4 in. were used for all measurements. The pulsed light source used in these experiments was a hot-cathode hydrogen lamp⁴ operated at peak currents of about 4.5 A with a duty cycle varying from 3 to 20%. The rise and fall times of the voltages applied to the lamp and to the grids were approximately 0.2 μ sec.

The gas samples used in these experiments were Airco Assayed Reagent Grade for krypton, xenon, carbon monoxide, and carbon dioxide. The manufacturer's mass spectrometric analysis shows that the impurity content of the krypton and xenon is below 0.01 mole %, of the carbon monoxide is 0.0275 mole % hydrogen and 0.030 mole % carbon dioxide and of the carbon dioxide is 0.005 mole % hydrogen. The ammonia and nitrous oxide were supplied in lecture bottles from the Matheson Company and were stated to have minimum purities of 99.99% and 98.0%, respectively. Both ammonia and nitrous oxide are liquids as supplied by the manufacturer and can be admitted to the tube in a purer form by filling the line connecting the tank to the inlet needle valve of the vacuum system with the liquid. In spite of the bake out (250°C) given to the connecting line, when the line was filled with ammonia vapor attachment occurred at the lower values of E/p and prevented electrons from reaching the second grid. The water vapor was prepared by multiple distillation and was supplied by W. M. Hickam of this Laboratory in a sealed glass ampule. The impurities in the deuterium were believed to have been less than 0.5% which is the maximum stated impurity level in deuterium as supplied by the Stuart Oxygen Company. No mass spectrographic analysis of the deuterium gas was supplied. The vacuum conditions before the admission of the gas were the same as described previously,² so that the impurities introduced by the system were negligible. Data were obtained at the various temperatures as described previously.² At 381, 410, and 443°K the tube was heated by an oven whose temperature was regulated to plus or minus one degree or better. Pressure and voltage measurements were made as described previously.²

IV. RESULTS

The drift velocities in krypton, and xenon are shown as a function of E/p in Fig. 2. The values of E/p are expressed in units of V/cm-mm Hg for an equivalent density of 300°K, i.e., $E/p = (E/N) \times 3.22 \times 10^{16}$ for all data given in this paper. Here N is the gas density. The

normalized pressures quoted are the values measured using the manometer system (at 300°K) and multiplied by 300/ T . Data are shown for E/p values from 2.6×10^{-4} V/cm-mm Hg at temperatures of 195, 300, and 368°K. The curves for argon from the previous paper² are shown to illustrate the similarity of these noble gases. The normalized pressures varied from 15.4 mm Hg at high E/p and 300°K to 885 mm Hg at low E/p and 195°K in krypton and xenon. Drift velocities are shown only for values of E/p such that the "time constant" for energy relaxation is much smaller than the drift time as done in the previous paper.² Our results are significantly higher than those of Bowe⁵ and lower than those of English and Hanna⁶ (not shown) in krypton over the common range of E/p . The larger drift velocities in krypton of English and Hanna for E/p of 0.02 V/cm-mm Hg and above have been attributed⁶ to impurities.

The drift velocities in nitrous oxide, carbon dioxide, ammonia, and water vapor are shown in Fig. 3. Data are shown for E/p values from 0.01 to 28 V/cm-mm Hg at temperatures from 195 to 443°K. The normalized pressures in nitrous oxide varied from 29.5 mm Hg at 300°K to 154 mm Hg at 195°K. These results are in good agreement with those obtained by Nielsen and Bradbury⁷ and by Bailey and Rudd⁸ over the common range of E/p . The drift velocity in nitrous oxide did not change when the gas temperature was changed from

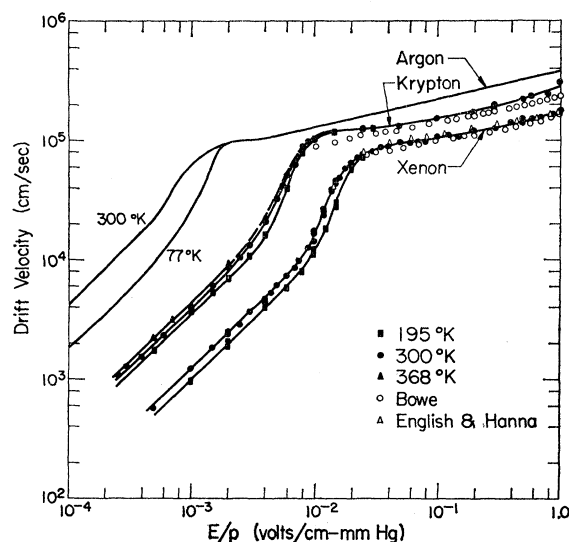


FIG. 2. Electron drift velocities in krypton and xenon. Electron drift velocities in argon from the previous paper are shown for comparison. The linear dependence of the drift velocity on E/p for $E/p < 2 \times 10^{-3}$ V/cm-mm Hg in krypton and for $E/p < 5 \times 10^{-3}$ V/cm-mm Hg in xenon as evidenced by the 45° slope on the log-log plot and the fact that the drift velocities depend upon gas temperature indicates that the electrons are in thermal equilibrium with the gas below these values of E/p .

⁵ J. C. Bowe, Phys. Rev. **117**, 1411 (1960).

⁶ W. N. English and G. C. Hanna, Can. J. Phys. **31**, 768 (1953).

⁷ R. A. Nielsen and N. E. Bradbury, Phys. Rev. **51**, 69 (1937).

⁸ V. A. Bailey and J. B. Rudd, Phil. Mag. **14**, 1033 (1932).

⁴ A. J. Allen and R. G. Franklin, J. Opt. Soc. Am. **29**, 453 (1939); and R. F. Weeks, *ibid.* **49**, 429 (1959). This lamp was obtained from Gerald Faust, Exton, Pennsylvania.

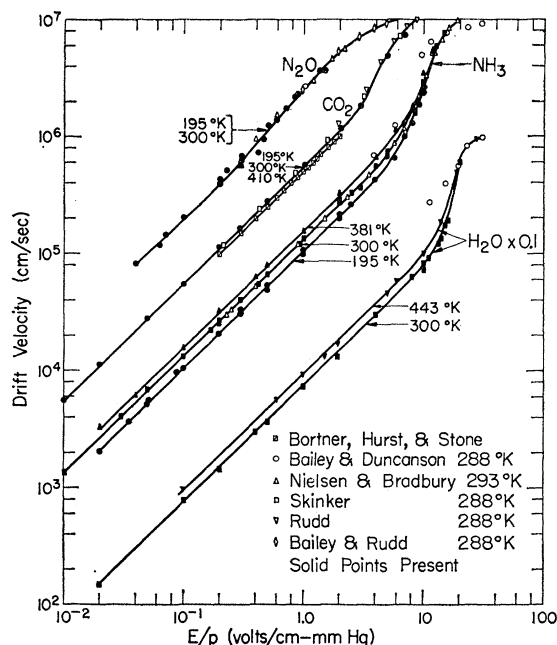


FIG. 3. Electron drift velocities in nitrous oxide, carbon dioxide, ammonia, and water vapor. Since the drift velocity of electrons in nitrous oxide and carbon dioxide is independent of the gas temperature at low E/p , the thermal region in nitrous oxide and carbon dioxide cannot be determined from these measurements. The electrons are in thermal equilibrium with the gas for $E/p < 2$ V/cm-mm Hg in ammonia and for $E/p < 5$ V/cm-mm Hg in water vapor. Note that the drift velocities in water vapor have been multiplied by 0.1 to avoid overlapping with the ammonia curves.

300 to 195°K at a fixed E/p . Therefore μN , the electron mobility times density, is not a function of temperature over this temperature range.

The normalized pressures in carbon dioxide varied from 2.19 mm Hg at 300°K to 328 mm Hg at 195°K. Good agreement is obtained with Rudd⁹ and Skinker¹⁰ over the common range of E/p ; however, our results are about 10% higher than those of Bortner, Hurst, and Stone.¹¹ Here again, the results were independent of temperature.

The normalized pressures in ammonia varied from 0.71 to 176 mm Hg at 300°K, from 2.0 to 65 mm Hg at 195°K, and from 2.6 to 85 mm Hg at 381°K. Good agreement is obtained with Nielsen and Bradbury⁷ over the common range of E/p . It should be noted that the drift velocities were observed to increase as the ammonia aged. This increasing drift velocity with time at high E/p and relatively low pressures is probably due to the dissociation of the ammonia.¹² This may account for the higher drift velocities observed by Bailey and Dun-

⁹ J. B. Rudd as quoted in R. H. Healey and J. W. Reed, *The Behavior of Slow Electrons in Gases* (The Wireless Press, Ltd., Sidney, 1941), p. 98.

¹⁰ M. F. Skinker, *Phil. Mag.*, **44**, 994 (1922).

¹¹ T. E. Bortner, G. S. Hurst, and W. G. Stone, *Rev. Sci. Instr.* **28**, 103 (1957).

¹² J. Knox, *Fixation of Atmospheric Nitrogen* (Gurney and Jackson, London, 1914) p. 65.

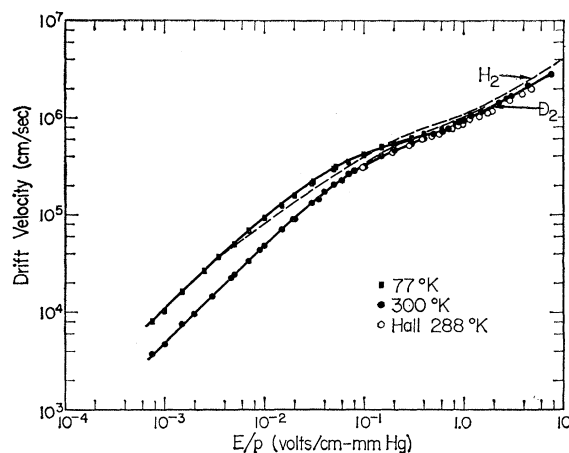


FIG. 4. Electron drift velocity as a function of E/p in deuterium at 77 and 300°K. For $E/p < 4 \times 10^{-3}$ the electrons are in thermal equilibrium with the gas at each temperature. The drift velocities of electron in hydrogen at 77 and 300°K obtained previously are shown by the dashed line for comparison.

canson¹³ for E/p between 4 and 15 V/cm-mm Hg. Thus, we find that at an E/p of 10 in gas which has been left in the system overnight at 381°K and a pressure of 3 mm Hg the drift velocity is 60% higher than that obtained with fresh gas. This change is consistent with the observation that the pressure had increased by 10%, presumably due to the dissociation of the ammonia. At 300°K, the apparent rate of dissociation was less; three days at least were necessary to cause 10% dissociation. In order to obtain consistent data, it was necessary to flush the system every day and draw fresh ammonia from the liquid phase as discussed previously.

The normalized pressures in water vapor varied from 1.2 to 24.6 mm Hg at 300°K and from 1.0 to 15.2 mm Hg at 443°K. Good agreement is obtained with Bailey and Duncanson¹³ for E/p between 20 and 30 V/cm-mm Hg; however, the difference below E/p of 20 V/cm-mm Hg is unexplained. Loeb¹⁴ suggests that some of the attachment observed in water vapor at E/p below 10 V/cm-mm Hg by Bradbury and Tatel¹⁵ may be due to impurities. Even at the saturation pressure in water vapor the current in our experiments is purely electronic and no evidence of attachment is found. Thus, if aggregates of H_2O molecules are present¹⁵ they do not lead to attachment. At an E/p of 0.02 V/cm-mm Hg and 300°K the transit time to the second grid was 6.6 msec. The decrease in the number of electrons reaching the second grid compared to the number reaching the first grid due to attachment is less than 10% for this measurement carried out at a pressure of 24.6 mm Hg. Therefore, ν_a/p , the attachment frequency divided by pressure, is less than 0.40 sec⁻¹ mm Hg⁻¹. This is approximately 10^{-3} times the upper limit found by

¹³ V. A. Bailey and W. E. Duncanson, *Phil. Mag.* **10**, 145 (1930).

¹⁴ See reference 3, Chap. V.

¹⁵ N. E. Bradbury and H. E. Tatel, *J. Chem. Phys.* **2**, 835 (1934).

Takeda and Dougal¹⁶ and 10^{-6} the value measured by Bradbury and Tatel¹⁵ after converting their data to give an attachment frequency.¹⁷ Measurements by Fox, Malmberg, and Gosser¹⁸ also confirm the absence of attachment in water vapor. It is, therefore, our opinion that all of the previous measurements of attachment in water vapor at E/p below 10 V/cm-mm Hg must have been due to impurities in the water vapor.

The drift velocities of electrons in deuterium are shown in Fig. 4. Data are shown for E/p values from 7.5×10^{-4} to 7.5 V/cm-mm Hg at 77 and at 300°K for normalized pressures between 1.74 and 660 mm Hg. The dashed curves are the drift velocities of electrons in hydrogen at 77 and 300°K as reported in the previous paper.² The agreement with Hall,¹⁹ who used a magnetic deflection method and calculated the drift velocities for a Maxwellian and Druyvesteyn distribution, is consistent with that found in hydrogen.²⁰ Only the values obtained from the Druyvesteyn distribution are shown.

The drift velocities in carbon monoxide are shown in Fig. 5. Data are shown for E/p from 0.001 to 10 V/cm-mm Hg at 77, 195, and 300°K. The normalized pressures in carbon monoxide varied from 3.4 to 511 mm Hg. Skinker and White²¹ obtained electron drift velocities in carbon monoxide by the magnetic deflection method; and at high E/p their values of drift velocity are 30% higher than reported here. The thermal values of electron drift velocity for the data at 300°K has scatter and may be questionable because electron attachment was observed. It is believed that the carbon monoxide reacted with the metallic parts of the vacuum system and formed compounds which result in electron loss by attachment. This excessive attachment was not detected at 77°K, 195°K and at pressures of 10 mm Hg or less at 300°K. The drift velocity curve at 77°K in CO resembles the 77°K drift velocity curve of N₂ obtained previously.² Both curves exhibit a minimum in drift velocity vs E/p . The region over which the drift velocity is nearly independent of E/p is much smaller in carbon monoxide than in nitrogen.

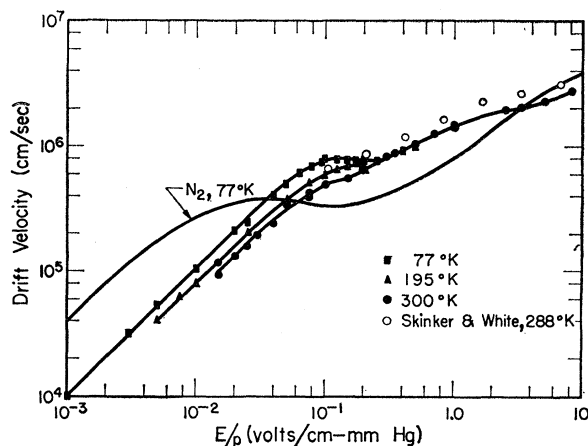


FIG. 5. Electron drift velocity as a function of E/p in carbon monoxide at 77, 195, and 300°K. For $E/p < 3 \times 10^{-2}$ the electrons are in thermal equilibrium with the gas at each temperature. The drift velocities obtained in reference 2 for nitrogen at 77°K are shown for comparison.

V. ANALYSIS OF DATA

In order to obtain momentum-transfer cross sections as a function of electron energy from these measurements of electron drift velocity, we must know the electron energy distribution. As in the previous paper² we make use of the fact that at the lowest values of E/p in all gases reported in this paper the drift velocity varies linearly with E/p and the electrons have a Maxwellian energy distribution with a temperature which is the same as that of the gas. We obtain the quantity μN , where μ is the electron mobility, for E/p small enough such that the above condition prevails at several temperatures. By choosing a functional behavior of μN in terms of gas temperature which fits our data, we can obtain momentum-transfer cross sections, σ , which are consistent with the drift velocity measurements and which are functions of electron energy. The procedure used to evaluate the σ 's is described in detail in reference 2.

The experimentally determined values of μN for $E/p \rightarrow 0$ from the data of Figs. 2 to 5 are given in Table I.

TABLE I. Experimental Values of μN at low E/p in $\text{cm}^{-1} \text{V}^{-1} \text{sec}^{-1}$

$T(^{\circ}\text{K})$	Kr	Xe	D ₂	CO
77			3.42×10^{23}	3.32×10^{23}
195	1.15×10^{23}	3.14×10^{22}		2.56×10^{23}
300	1.32×10^{23}	3.87×10^{22}	1.55×10^{23}	2.08×10^{23}
368	1.41×10^{23}			
$T(^{\circ}\text{K})$	CO ₂	H ₂ O	NH ₃	N ₂ O
195	1.83×10^{22}		3.35×10^{21}	6.71×10^{22}
300	1.81×10^{22}	2.38×10^{21}	4.34×10^{21}	6.69×10^{22}
381			5.15×10^{21}	
410	1.75×10^{22}			
443		3.00×10^{21}		

¹⁶ S. Takeda and A. A. Dougal, J. Appl. Phys. **31**, 412 (1960).

¹⁷ The attachment in water vapor in the papers by Bradbury and Tatel and by Takeda and Dougal is given in terms of the attachment probability h , the probability of attachment per collision. The attachment frequency is therefore given by h times an average collision frequency calculated from our drift velocity data. Our drift velocity experiment actually gives a measure of the attachment frequency directly. In all experiments the electrons are thermal; i.e., in those of Bradbury and Tatel and in our experiments at $E/p < 5$ and in the afterglow experiments of Takeda and Dougal in the late times.

¹⁸ R. E. Fox, P. R. Malmberg, and R. B. Gosser, Rev. Sci. Instr. **32**, 898 (1961).

¹⁹ B. I. H. Hall, Australian J. Phys. **8**, 468 (1955).

²⁰ L. S. Frost and A. V. Phelps, Phys. Rev. **127**, 1621 (1962). The results obtained by Hall for H₂ are consistently 10–15% below those of J. S. Townsend and V. A. Bailey, Phil. Mag. **42**, 873 (1921). Since the Townsend and Bailey results for H₂ are in good agreement with theory, we suspect that Hall's values for D₂ are also low.

²¹ M. F. Skinker and J. V. White, Phil. Mag. **46**, 630 (1923).

The values are averages of all data in the thermal region for each gas at each temperature. The standard error is less than 2% for all values given. Systematic errors are estimated to be less than 5%. In the cases of carbon dioxide and nitrous oxide, the variation with temperature is comparable with the standard error; therefore, it is assumed that μN is independent of temperature and is equal to 1.80×10^{22} for carbon dioxide and 6.70×10^{22} for nitrous oxide in $\text{cm}^{-1} \text{V}^{-1} \text{sec}^{-1}$.

The measured values of μN for krypton and xenon were fitted to several two-term power series which yield momentum transfer cross sections, σ_x , as shown in Fig. 6. The subscript x is used to distinguish various approximations to the temperature dependence of the measured μN values. For krypton the derived cross sections are

$$\begin{aligned}(\sigma_1)^{-1} &= 3.68 \times 10^{14} + 4.05 \times 10^{16} u^{3/2} \text{ cm}^{-2}, \\(\sigma_2)^{-1} &= 1.59 \times 10^{14} + 1.53 \times 10^{15} u \text{ cm}^{-2}, \\(\sigma_3)^{-1} &= -5.22 \times 10^{14} + 6.92 \times 10^{15} u^{1/2} \text{ cm}^{-2}.\end{aligned}$$

Here u is the electron energy in eV. For xenon the derived cross sections are

$$\begin{aligned}(\sigma_1)^{-1} &= 8.40 \times 10^{13} + 1.41 \times 10^{16} u^{3/2} \text{ cm}^{-2}, \\(\sigma_2)^{-1} &= 1.04 \times 10^{13} + 5.46 \times 10^{15} u \text{ cm}^{-2}, \\(\sigma_3)^{-1} &= -2.06 \times 10^{14} + 2.27 \times 10^{15} u^{1/2} \text{ cm}^{-2}.\end{aligned}$$

The corresponding curves in argon from the previous paper² are shown to illustrate the similarity between the cross sections in these noble gases. The range of the validity of this analysis extends from about $1/2$ of kT/e

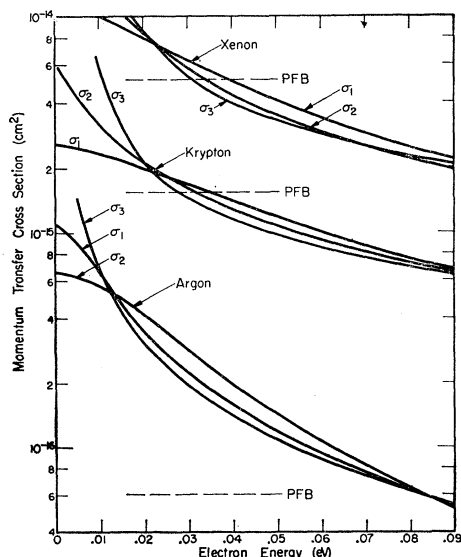


FIG. 6. Momentum transfer cross sections in krypton and xenon as a function of electron energy for three choices of the power series expansion of μN . The curves obtained for argon are shown to illustrate the similarity of these gases. Note that the cross sections are plotted on a logarithmic scale. The results of Phelps, Fundingsland, and Brown (PFB) are also shown.

at the lowest temperature to about twice kT/e at the highest temperature of the measurements or between the areas where these curves cross. Good agreement is obtained in krypton and xenon with Phelps, Fundingsland, and Brown (PFB)²² who assumed that the cross section was constant. If their data is reanalyzed using the correct energy dependence, their cross sections would agree within experimental error with those shown over the energy range 0.015 to 0.06 eV in krypton and xenon.

The derived cross section for water vapor, ammonia, carbon dioxide, and nitrous oxide are shown in Fig. 7 over energy ranges estimated to be valid for each gas.

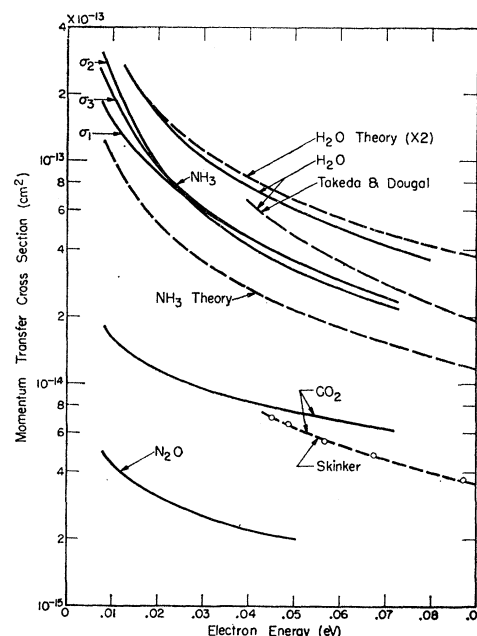


FIG. 7. Momentum transfer cross sections in water vapor, ammonia, carbon dioxide, and nitrous oxide as a function of electron energy. Note that the cross sections are plotted on a logarithmic scale.

The derived curves in ammonia are given by

$$\begin{aligned}(\sigma_1)^{-1} &= 4.93 \times 10^{13} u^{1/2} + 1.51 \times 10^{15} u^{3/2} \text{ cm}^{-2}, \\(\sigma_2)^{-1} &= (-0.337 u^{1/2} + 7.52 u) \times 10^{14} \text{ cm}^{-2}, \\(\sigma_3)^{-1} &= (4.41 u + 5.42 u^{3/2}) \times 10^{14} \text{ cm}^{-2}.\end{aligned}$$

Only one cross section is shown for water vapor and is given by

$$(\sigma)^{-1} = (2.74 u + 2.54 u^{3/2}) \times 10^{14} \text{ cm}^{-2}.$$

The σ_3 curve for NH_3 and the σ curve for H_2O are nearly the same functional form as the theory of Altshuler²³ and are approximately 60% higher than Altshuler's theory over the energy range of 0.01 to 0.08 eV in the

²² A. V. Phelps, O. T. Fundingsland, and S. C. Brown, Phys. Rev. **84**, 559 (1951).

²³ S. Altshuler, Phys. Rev. **107**, 114 (1957).

case of ammonia and from 1.8 to 2 times the theory in the case of water vapor. The cross section in water vapor derived by Takeda and Dougal¹⁶ shows a more rapid fall off with energy than in the present derived cross section but would intercept the present curve at approximately 0.03 eV.

The cross sections in carbon dioxide and nitrous oxide are consistent with a constant μN and are given by

$$\sigma(\text{CO}_2) = 1.64 \times 10^{-15} u^{-1/2} \text{ cm}^2,$$

$$\sigma(\text{N}_2\text{O}) = 6.1 \times 10^{-16} u^{-1/2} \text{ cm}^2.$$

The cross sections in carbon dioxide agree with an extension of that calculated by Skinner¹⁰ at electron energy of 0.035 eV but varies as $1/u^{1/2}$ instead of $1/u$. The cross section in nitrous oxide is equal to 0.37 times the cross section in carbon dioxide and varies as $1/u^{1/2}$ in the energy range of 0.01 to 0.05 eV.

The cross section in deuterium consistent with the drift velocity measurements is $\sigma^{-1} = (1.29 - 3.36 u) \times 10^{15} \text{ cm}^{-2}$ which differs from that of hydrogen previously reported² by less than 1% over the energy range of 0.003 to 0.05 eV. Therefore, within the accuracy of our measurements the elastic scattering cross section in deuterium is identical to that in hydrogen for electron energies below 0.05 eV as one would expect.²⁴

The measured values of μN in carbon monoxide for 77 and 195°K were fitted to a two term power series which yields a cross section as shown in Fig. 8. The μN at 300°K was not used due to the excessive attachment observed at the lower values of E/p at 300°K. Even so, the μN value at 300°K was only 10% higher than the curve fitted to the 77 and 195°K values. The derived cross section is given by

$$\sigma^{-1} = 1.29 \times 10^{16} u^{1/2} - 1.01 \times 10^{17} u^{3/2} \text{ cm}^{-2}.$$

Since carbon monoxide and nitrogen are isoelectronic and similar low-energy electronic states exist for both, one would expect the momentum-transfer cross section in carbon monoxide to be similar to that in nitrogen except for the effect of the dipole moment of carbon

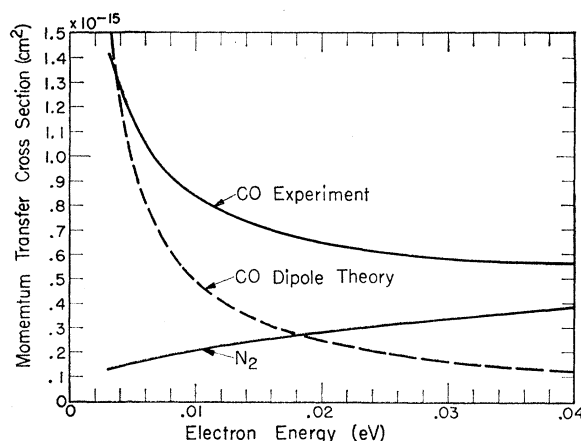


FIG. 8. Momentum transfer cross section in carbon monoxide as a function of electron energy. A theoretical curve based on Altshuler's analysis and the cross section in nitrogen are shown for comparison.

monoxide. As shown in Fig. 8, the derived cross section is qualitatively equal to the cross section in nitrogen^{2,20} plus a contribution due to the dipole moment interaction as proposed by Altshuler.²³

VI. SUMMARY

Electron drift velocities in atomic and molecular gases measured at very low E/p have been used to obtain the cross section for momentum transfer collisions in the energy range from 0.003 to 0.08 eV which are consistent with the observed mobilities. The technique described in this paper makes measurements possible at energies not available with present beam experiments so that one is willing to tolerate the lack of energy resolution. Drift velocity data of all gases in this and the earlier paper in tabulated form will be available upon request.

ACKNOWLEDGMENTS

The authors wish to express their appreciation for valuable discussions of this work with their associates in the Atomic Physics Group.

²⁴ E. Gerjuoy and S. Stein, Phys. Rev. **98**, 1848 (1955).