A Survey of Electron Swarm Data

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An electron swarm consists of a small number density n of electrons in a gas of much higher number density N. The mean energy and energy distribution of such a swarm are determined by the value of E/N, where E is the electric field. At any given value of E/N the swarm may be characterized by the values of eight parameters, viz; drift velocity, diffusion coefficient, (diffusion coefficient)/mobility, excitation coefficient, electron attachment coefficient, electron detachment coefficient, ionization coefficient, recombination coefficient. In this survey, data on these parameters obtained by a variety of experimental techniques are collected, discussed, and compared graphically. Also included on the graphs are computed values of the parameters obtained in many cases from cross sections and energy distributions chosen to give the best fit with the swarm data. Selected tabulations of the data are also given except in cases for which the accuracy of the data is not sufficient to warrant numerical presentation. The mean energy of the electron swarms ranges from thermal to several electron volts and the gases for which data are given are the rare gases, the common molecular gases (H_2, N_2, O_2, CO, NO, CO_2, NO_2) and air. The survey also contains an extensive bibliography which includes references (i) to publications on electron swarms in a much wider range of gases than those for which data are given and (ii) to papers concerned with energy distributions, conductivity, and ionization coefficients in crossed electric and magnetic fields in addition to those relating to the eight parameters listed above.

Key words: Electrical breakdown of gases; electrical discharges; electron attachment coefficient; electron detachment coefficient; electron diffusion coefficient; electron drift velocity; electron excitation coefficient; electron-ion recombination coefficient; electron ionization coefficient; electron swarm; electron transport coefficients; ionized gases.

Contents

1. Introduction

In order to understand many types of plasma and ionized gases, a knowledge is required of the behavior of mixed swarms of charged and neutral particles under various conditions of pressure (particle density) and temperature in the presence of electric and magnetic fields.

The behavior of electron swarms is characterized by a number of parameters that are determined experimentally in the laboratory. These parameters may, for convenience, be listed as follows:

(1) the drift velocity W of the electrons in an electric field E;

(2) the ratio of the diffusion coefficient D to the drift velocity, usually expressed as D/μ where $\mu = W/E$ is the mobility; this ratio is a measure of the mean energy of the electrons;

(3) the diffusion coefficient of electrons D;

(4) the electron attachment coefficient η;

(5) the detachment coefficient of electrons from negative ions δ (strictly a property of ion swarms but often measured in electron swarm experiments);

(6) the electron excitation coefficient ϵ;

(7) the primary ionization coefficient α;

(8) the coefficient of recombination of electrons with positive ions r.

Values of the above coefficients are usually determined for gas pressures in the range from about 1 to 1000 Torr (number density N from about 3.5×10^{16} to 3.5×10^{19} molecules/cm^3) at neutral gas temperatures in the range from about 50 to 500 K. By definition, the number density of electrons in a swarm is much less than that of the gas in which it moves, and the dominant collisions are consequently those between electrons and gas atoms. Thus, since the determination of most of the above properties requires the application of an electric field, the mean energy of the electrons is in general higher than that of the neutral gas (up to typically a factor of 50 times greater at $E/N \sim 150 \times 10^{-17}$ V. cm^2) and the electron energy distribution is not Maxwellian.

In some experiments, however, especially in most of those on recombination and on the measurement of coefficients at very low values of E/N, the electrons have a Maxwellian distribution. In these cases, rate coefficients determined in the laboratory may be directly applicable, for example, to processes occurring in the ionosphere.

Among the interactions of importance in determining the behavior of swarms are those of electrons with neutral particles, electrons with ions, and negative ions with neutral particles. Thus, in addition to their intrinsic value, the swarm data can be used to supplement information obtained from direct measurements of cross sections. The use of swarm data is of particular value both for the determination of cross sections at low electron energies, where direct measurements of cross sections are notoriously difficult, and for obtaining information about three-body processes which are insignificant at the particle densities usually used in beam experiments.

In order to obtain cross sections from swarm data it is, however, necessary to know the energy distribution under the conditions of the experiment, and this presents considerable difficulties. Little experimental evidence on electron energy distributions under swarm conditions is available, although there have been a few recent measurements [1651].[1] There have been considerable recent theoretical advances in the treatment of the problem [181, 218, 260, 1062, 2553],[1] in which self-consistent sets of cross sections for momentum transfer and for some inelastic processes have been obtained. The method used was to assume reasonable, energy-dependent cross sections, to integrate the Boltzmann equation numerically in order to obtain an energy distribution, and then to use this distribution together with the assumed cross sections to determine certain swarm coefficients such as W and D/μ. The assumed cross sections were then adjusted in order to give the best fit between calculated and observed swarm data.

Eventually, it is conceivable that the stage may be reached at which the cross sections of all electron collision processes are known, together with the energy distribution of an electron swarm under any given set of conditions. At present, however, the coefficients representing the behavior of the swarm form a necessary "half-way house," as it were, giving information that is useful in the solution of a wide range of fundamental and applied problems, from the determination of cross sections and energy distributions on the one hand, to the understanding of the behavior of ionized gases in laboratory devices and in astrophysical phenomena on the other. There is thus considerable need for an up-to-date compilation of available data, and towards this end a bibliography of electron swarm data was started in 1966. An interim version of this bibliography appeared as JILA Information Center Report No. 4 in October 1967. This bibliography has been completed and brought more up-to-date and is given below in sections 4 and 5. In addition, a data survey for the inert and the more common molecular gases has been carried out and is given in section 3. The effective terminal date for the comprehensive literature search for the bibliography was December 1968, but a more selective search, related to the data survey but including other bibliographic material, was continued until the end of 1972.

2. Selection and Arrangement of Data

2.1. Symbols and Units

As mentioned in section 1, the mean energy of an electron swarm in a given gas depends on the value of E/N. Thus the coefficients which characterize the

[1] Numbers in brackets refer to references listed in section 5.2.

behavior of swarms are usually presented as functions of E/N. Until recently, however, it has been common practice to use E/p_0 (where p_0 is the gas pressure reduced to 0 °C) rather than E/N and in view of this both E/p_0 and E/N are given in all graphs in order to help familiarize the conversion from E/p_0 to E/N. An increasingly widely used unit in which to express the value of E/N is the Townsend (1 Td $= 10^{-17}$ V cm^2), first suggested by Huxley, Crompton, and Elford (Brit. J. Appl. Phys. **17**, 1237, 1966).

With the exception of the drift velocity and the diffusion coefficient, the coefficients with which we are concerned can be expressed either (a) as rate coefficients or (b) as coefficients per unit drift distance in the direction of the electric field. There appear to be no generally agreed symbols for the full range of coefficients discussed, so in an attempt to achieve at least internal consistency, the following nomenclature is used here:

a) *Rate coefficients* are denoted by the appropriate lowercase type symbol with a suffix when appropriate to denote whether it is a two-body or a three-body reaction, e.g., the symbol representing three-body attachment rate coefficient is a_3;

b) *Coefficients* (per unit drift distance) are denoted by a lowercase Greek letter, e.g., the symbol for the attachment coefficient per unit drift distance is η. If the nature of the reaction is known, a subscript is added to denote whether it is a two- or three-body reaction, e.g., η_3 denotes the three-body attachment coefficient.

The relationship of the rate coefficient per unit drift distance to the collision frequency depends on the nature of the process. For a two-body process (such as ionization or radiative attachment, for example) the *collision frequency* for a given process ν_2, say, is related to the *coefficient* Π_2 and the *rate coefficient* p_2 for this process by

$$dn = n\Pi_2 dx = n\Pi_2 W dt = n\nu_2 dt = np_2 N dt,$$

where dn is the number of new electrons formed by a concentration n electrons in a drift distance dx or in a time dt and W is the electron drift velocity.

Thus $\Pi_2 = \nu_2/W = p_2 N/W$, Π_2 being in units of cm^{-1}, ν_2 in s^{-1} and p_2 in cm^3 s^{-1}.

For three-body processes (such as three-body attachment or recombination) on the other hand, the collision frequency ν_3, coefficient per unit drift distance Π_3, and rate coefficient p_3 for the process are related by

$$dn = n\Pi_3 dx = n\Pi_3 W dt = n\nu_3 dt = np_3 N^2 dt,$$

so that $\Pi_3 = \nu_3/W = p_3 N^2/W$, Π_3 being in units of cm^{-1}, ν_3 in s^{-1} as before, but p_3 in cm^6 s^{-1}.

A complete list of the symbols assigned to each of the coefficients and other parameters together with the units in which they are measured is given in section 6.

2.2. Scope and Arrangement of Data

An arbitrary choice has been made to limit the data presented to those gases that are of most general interest, viz: the monatomic gases, the common molecular gases H_2, N_2, O_2, CO, NO, CO_2, and air.

The aim is to provide a collection of the most reliable data on these gases and in order to avoid confusion, much of the earlier data, which has been superseded by values obtained with higher purity gas samples, is omitted. Since the coefficients are dependent on E/N rather than on E/p, results from papers that do not give the gas temperature to which the gas pressure corresponds are excluded unless there is a dearth of other data available. In these cases, the values of E/N are calculated assuming a stated value of the temperature and if they are the only data available the values of E/N are designated by $(E/N)_{Est}$ in graphs and tables. Other considerations relevant to specific coefficients are given in the introduction to the appropriate section and in the text accompanying the diagrams.

The collected data are presented in both graphical and tabular form. Except for data excluded for the reasons given above, an attempt has been made to include all published data for the coefficient involved on any given graph. Thus the graphs provide an indication of the amount and range of data available in each case and of the degree of agreement which exists.

On the other hand, the tables which are grouped at the end of each section have mostly been prepared with a view to providing usable accurate sets of numerical values (where these are available) rather than for comparative purposes. Thus, for cases in which there are a number of sets of experimental and theoretical results in good agreement, if there is an experimental set of data which seems more accurate than the others, this has often been the only set tabulated. Where there are no published experimental values, theoretically computed values have been used in some cases.

For the coefficients discussed in sections 3.1 to 3.7, however, the theoretical results have, in most cases, been obtained, as indicated in the text, by using cross sections chosen to give the best fit with the experimental swarm data. The theoretical values on the graphs in these sections thus do *not* provide an independent confirmation of the experimental data, themselves. They are included on the figures to show the cases in which such calculations have been made and the degree of agreement which has been achieved using this procedure. In section 3.8, on the other hand, the theoretical values for the recombination coefficient do *not* depend on the experimental values for r and thus, where they exist, provide an independent comparison.

Where there is a considerable spread in the available data and no clear reason to prefer one set of data over the others, no table has been included because values, accurate to within the spread, can readily be obtained from the graphs. Theoretical data are often presented as continuous curves in the original papers and the theoretical points on many of the graphs given in this review represent no more than an arbitrary selection of points, chosen at sufficiently frequent intervals on the original curves to indicate their trend. There may thus well be more points given on the graphs than were originally calculated. Occasionally, in figures on which there are a large number of results in close agreement, a few of the intermediate points in some sets of data have been omitted for clarity. Unless otherwise stated the data given were obtained at ambient temperatures. Temperature is mentioned for specific cases only when data are given for both ambient and other temperatures.

2.3. Method of Preparation of Figures and Tables

Where the original data were published in tabular form, figures were prepared directly from the tables. In most cases, however, the data were published in the form of graphs and in these cases the graphs were enlarged and the co-ordinates of the data points obtained in digital form using a Gerber Digital Reduction System connected to an IBM card punch. The least count of the Gerber reader is 0.1 percent of full scale. The digital data were stored on magnetic tapes and the figures then photocomposed from these tapes on a DD.280 Cathode ray tube at the NOAA Boulder Laboratories computing facility. The plotting error amounts to less than 0.5 percent near the largest value on any particular graph and is somewhat larger where the coefficient is small (< 10 percent of the largest value).

For cases in which the original data were in tabular form, the original tables are reproduced. Where the data were given graphically, the co-ordinates of the data points obtained using the Gerber Digital Reduction System were used to prepare the tables. Since this system gives values of each co-ordinate to four significant figures, a decision on how many of these figures to retain was required. In the published paper, the errors in the coefficient are often not estimated and, even more frequently, no estimate is given in the experimental papers of the errors in the measured parameters that give the values of E/N. However, the value of E/N is seldom determined more accurately than to within about 0.1 percent and the coefficients themselves are usually not determined to better than within about 1 percent. In general, in these circumstances, therefore, as far as the coefficients are concerned, three significant figures are retained for values lying between 1.00 and 2.99 and two significant figures for values lying between 3.0 and 9.9, while in the case of E/N, four significant figures are retained for values lying between 1.000 and 2.999 and three significant figures for those between 3.00 and 9.99. Particular cases in which this procedure is not appropriate are indicated where the tables occur and the procedure adopted is also given there.

3. Data Survey

3.1. Drift Velocity

An electron swarm in the presence of a steady electric field both diffuses and moves as a whole in the direction of the field. In the steady state, the center of mass of the swarm attains a velocity W, which may be expressed [1432] (see also W. P. Allis, in *Handbuch der Physik*, S. Flugge, ed., Springer, Berlin, 1956, Vol. 21, p. 383), in terms of the ratio E/N and of atomic parameters by the relationship [2]

$$W = -(4\pi Ee/3Nm)\int_0^\infty (c^2/q_m)(df/dc)dc, \qquad (1)$$

where e and m are the electronic charge and mass respectively, c is the speed of an electron, q_m the momentum transfer cross section which is a function of the speed and f the speed distribution function normalized through the equation

$$4\pi\int_0^\infty f(c)c^2dc = 1.$$

Using pulse techniques, W may be determined experimentally by direct measurement of the time taken for the swarm to move through a measured distance. At relatively high values of E/N, where the short transit times make precise direct measurements of this sort difficult, many of the data available were determined using a less direct method originally devised by Townsend and Tizard [2104] before the advent of pulse techniques. In this method, the deflection, in a direction perpendicular to both the electric and magnetic fields, of a swarm travelling a measured distance under the influence of crossed uniform electric and magnetic fields is determined. From measurements of this sort, a quantity W_M, which is related to W by

$$W_M = \psi W, \qquad (2)$$

is determined. The constant ψ is sometimes known as the magnetic deflection coefficient [181], and often has a value near unity (see for example Townsend, Phil. Mag. **23**, 880, 1937, and Huxley, Australian J. Phys. **13**, 718, 1960). It can be shown that

$$\psi = \frac{3\int_0^\infty (c/q_m^2)(df/dc)dc}{4\pi\left[\int_0^\infty (c^2/q_m)(df/dc)dc\right]^2}, \qquad (3)$$

for small magnetic fields B such that $\omega = eB/m \ll Nq_mc$. The value of ψ thus depends on the distribution function

[2] This relationship is strictly true only for the case of elastic collisions but in fact has a much wider range of applicability (see R. W. Crompton, Adv. in Electronics & Electron Physics **27**, 1, 1969).

and on the variation of q_m with c, being unity if cq_m is a constant. Where they are available, the values of both W and W_M are given in the following graphs and tables for the gases listed in section 2.2.

3.1.a. Drift Velocity—Helium

Much attention has been paid to the region of low values of $E/N < 13 \times 10^{-17}$ V cm^2, because this is a particularly favorable one in which to obtain values of q_m from data on drift velocities. The experimental values obtained in this region are given in figure 1.1. Consideration has to be given to the effect of diffusion which leads to a correction of the measured value of the drift velocity by a factor of the form $[1+(c_1/d)(D/W)]$ where d is the drift distance, D the diffusion coefficient and c_1 is a dimensionless constant. It has however been shown [1434] that under usual experimental conditions this correction is small (< 10 percent).

The two most recent sets of data [530, 2433] are in good agreement. The error in the data of Crompton, Elford, and Jory [2433] is estimated as less than 1 percent over the whole range investigated and less than 0.5 percent for $E/N < 1.82 \times 10^{-17}$ V cm^2. Accordingly, this complete set of data is tabulated in table 1.1(a) together with the results of Pack and Phelps [530] at values of E/N below those investigated by Crompton et al. (Crompton et al. indicate that the data of Bowe [1623] have been revised since they were published and now agree within 2 percent of their data, but no details are available.)

There have been a number of recent investigations of the variation of W with gas pressure in helium both at room temperature [4055, 4058] and at 77 K [4913, 4355]. No significant variation of W with pressure was observed for N up to about 3×10^{20} cm^{-3} and E/N down to about 0.008×10^{-17} V cm^2. At higher pressures, however, the decrease in W with increasing N shown in table 1.1(b) was reported [4055], the accuracy of most of the measurements being estimated to be within 1 or 2 percent.

The results of a number of theoretical computations of W in this region of low values of E/N are given in figure 1.2. It can be seen that the different theoretical treatments give values in general agreement with each other and with experiment, even though they are based on different assumptions and different variations of q_m with energy. Two of the recent sets of data [1062, 2433] in figure 1.2 were obtained by an iterative process involving numerical integration of the Boltzmann equation and are in detailed agreement within the experimental error with the two most recent sets of accurate experimental data. The difference in the values of q_m required to give this detailed agreement with the two different sets of experimental data is small, being about 15 percent at 3 eV but less than 3 percent below 0.6 eV. In both cases a useful cross-check on the values of q_m obtained was provided by using them to calculate values of other swarm parameters which were compared with experimental values (see W_M and sec. 3.2.a). Also given in figure 1.2 are the theoretical data resulting from a stochastic treatment [3463] of the problem.

At higher values of E/N, values of W for electrons in glow discharges in helium have been obtained experimentally from measurements on the positive columns of such discharges. The results which are shown in figure 1.3 and table 1.2 are in good agreement with each other.

There are no completely satisfactory theoretically computed values of W for helium for $E/N > 1.3 \times 10^{-16}$ V cm^2. The most reliable to date are those obtained by Monte Carlo methods [3897, 5490]. Both these sets of data are in good agreement with experiment and one is shown in figure 1.3. The treatment, however, effectively ignored the effect of electron diffusion and the production of slow electrons by ionization on the energy distribution [see 3752].

Results [530, 4355] illustrating how the drift velocity at very low values of E/N varies with temperature in the range from room temperature down to 77 K are shown in figure 1.4 and the values obtained at 77 K tabulated in table 1.1(c).

Other measurements [1714, 2266] at temperatures near 4 K and at pressures up to the saturated vapor pressure show that the mobility in that region lies well below the kinetic theory values, being a factor of about 10^4 smaller at the saturated vapor pressure.

3.1.b. Values of W_M—Helium

Values of W_M accurate to within about ±2 percent obtained recently by Crompton, Elford, and Jory [2433] are compared in figure 1.5 with the earlier values of Townsend and Bailey [201]. The values of q_m obtained by Crompton et al. from considerations of their experimentally measured values of W (see previous section) were used to calculate W_M and these computed values are given together with their experimental data for W_M in table 1.3.

3.1.c. Drift Velocity—Neon

A number of direct measurements of drift velocities have been made for neon for values of E/N below 4×10^{-17} V cm^2. Robertson [4862] has shown that low levels of N_2 impurity (~20 ppm) can significantly affect the values of W in neon and the most reliable sets of data seem to be those of Nielsen [1387], of Pack and Phelps [530] and of Robertson [4862], the latter being the most accurately determined with an estimated error of ±1 percent. These results which were obtained at ambient temperatures are given in table 1.4(a) and compared with the other results in figure 1.6.

Robertson was also able to find values of the momentum transfer cross section which gave calculated values of the drift velocity in agreement with experiment and these values are also shown in figure 1.6.

Values obtained [4862] at a temperature of 77 K are also given in figure 1.6 and table 1.4(b).

There are no experimental values of W in neon for $E/N > 4\times10^{-17}$ V cm^2 measured under swarm conditions. Values of W for glow discharge in neon have however been obtained [2164, 5780] by measuring the current and electron concentration. These values are compared in figure 1.7 with the most reliable theoretically computed swarm values available, which are those of Thomas and Thomas [3752] who obtained good agreement between results calculated using a numerical solution of the Boltzmann equation [3753] and using Monte Carlo methods [3752].

3.1.d. Values of W_M – Neon

The only values of W_M obtained for neon using the Townsend method are those of Bailey [2280] for neon known to contain 1 percent helium. (See fig. 1.8.) Robertson [4862] has suggested that the gas may well have also contained small amounts of molecular impurities (see 3.2.b).

3.1.e. Drift Velocity – Argon

There have been a large number of investigations of the drift velocity of electrons in argon giving data mainly in the range $3\times10^{-18} < E/N < 4\times10^{-16}$ V cm^2. During the course of this work, it has become clear [732, 2042] that small amounts of impurity (< 1 percent) particularly of molecular gases such as N_2 give rise to very different values (typically a factor of two higher) than those obtained for pure argon. Relatively low values characteristic of pure argon have been obtained in several investigations and these results are shown in figure 1.9 and given in table 1.5 from which it can be seen that there is a fair measure of agreement. Theoretical values in the same range of values of E/N are shown in figure 1.10 from which it can be seen that there is a general agreement both between them and with the experimental results shown in figure 1.9, although a variety of methods and assumptions have been used.

The theoretical values calculated by Englehardt and Phelps [292] were obtained on the basis of values of q_m (as a function of energy) determined by comparing experimental and theoretical values of both W and D/μ over the range $6\times10^{-21} < E/N < 10^{-15}$ V cm^2. (The values of q_m have, however, been questioned, see Golden, Phys. Rev. **151**, 48, 1966.) The calculated values of W for the lower end of this range [1062] are in detailed agreement with the experimental data at temperatures of 300 K and 77 K as shown in figure 1.11. The experimental values are given in table 1.6 together with one theoretical value at the lowest value of E/N.

There are fewer experimental data available for $E/N > 4\times10^{-16}$ V cm^2, those of Jager and Otto [2153] of Wagner [4971] and of Brambring [4944] being shown in figure 1.12 and in table 1.7. These data are in good agreement with each other and fit smoothly with the values of W obtained at low values of E/N shown in figure 1.9. Also shown in figure 1.12 are the theoretical values computed by Golant [881] on the basis of smoothed experimental collision cross sections and the energy distribution which he calculated and which was found to be in good agreement with that of Englehardt and Phelps [292] at $E/N = 3\times10^{-16}$V cm^2.

Measurements [4058, 5188] covering a total range of pressure from about 750 to 76,000 Torr show no variation of drift velocity with pressure outside the experimental error.

3.1.f. Values of W_M – Argon

The only published experimental data for W_M for argon are the early results of Townsend and Bailey [197, 199]. The results from [199] which were for less contaminated gas samples are shown in figure 1.13 and table 1.8 together with the theoretical values by Englehardt and Phelps [292] calculated using their values of q_m obtained from consideration of data on W and D/μ. A possible explanation of the difference is that the theoretical data refer to the limit of vanishingly small magnetic fields and Chen's calculations (J. Appl. Phys. **37**, 2205, 1966) of the Hall effect show that W_M is lower at higher fields.

3.1.g. Drift Velocity – Krypton and Xenon

Few experimental data are available for xenon and krypton, the most reliable at low values of $E/N < 4\times10^{-17}$ V cm^2 being those of Pack, Voshall, and Phelps [439] whose results are shown in figure 1.14(a) and given in tables 1.9 and 1.10.

Frost and Phelps [1062] were able to determine values of q_m as a function of energy which gave good agreement with the above experimental data, although in the case of krypton the values of q_m required lie well below the measured values (Ramsauer, Ann. Physik **12**, 529, 1932) of total cross section and other calculated values (O'Malley, Phys. Rev. **130**, 1020, 1963) of q_m; there are differences also in the case of xenon when compared with other results.

At higher values of E/N the only data available are those of Wagner [4971] for xenon for $112\times10^{-17} < E/N < 255\times10^{-17}$ V cm^2 which are shown in figure 1.14(b) and given in table 1.10(a).

There are no published values of W_M for either krypton or xenon.

3.1.h. Drift Velocity – Hydrogen

A particularly thorough investigation of W for hydrogen over the range $2.8\times10^{-19} < E/N < 5.7\times10^{-16}$ V cm^2 was carried out by Lowke [1155], who showed that using modern experimental techniques and making the necessary corrections for diffusion [see also 1434], measurements of W can be made to within 1 percent. His results for $E/N < 2.82\times10^{-17}$ V cm^2 are shown in figure 1.15 together with those of Pack and Phelps [530] and Bradbury and Nielsen [1381] with which they agree within the experimental error. The two recent sets of data [530, 1381] are given in table 1.11(a).

In this region of low E/N, the values of W depend on the gas temperature, and the results given in figure 1.16(a) (for clarity of presentation the figure has been limited to values of $E/N < 2.82 \times 10^{-18}$ V cm^2 and the data at a temperature of 195 K in [530] omitted) show that the two published sets of experimental data [530, 1155] for this temperature dependence agree well with each other and with the theoretically computed values [181, 3463]. The experimental data at 77 K are given in table 1.11(b).

The majority of the results of the relatively large number of investigations which have been made of W for hydrogen lie within the range $2.8 \times 10^{-17} < E/N < 113 \times 10^{-17}$ V cm^2, and most of the published data (which it is possible to express unambiguously in terms of E/N) are shown in figure 1.17 and selected values given in table 1.12. It can be seen that, bearing in mind that the experimental error increases to about 2 or 3 percent at the upper end of this range, there is good agreement between the various sets of data.

Theoretical values of W were obtained by Frost and Phelps [181] on the basis of a numerical solution of the Boltzmann equation and as can be seen from figures 1.16(a) and 1.17 these values were in good agreement with experiment for a determined set of values of the appropriate momentum transfer, rotational and vibrational cross sections involved. The theoretical values of W obtained for a temperature of 77 K by Bell and Kostin [3463] using a stochastic treatment also agree well with experiment.

In a recent interesting series of experiments [4450, 4913, 4916, 4484] aimed at investigating the pressure dependence of the drift velocity [4913] and determining cross sections for rotational and vibrational transitions [4450, 4484] in hydrogen, measurements have been made of the drift velocity for both normal and para-hydrogen at 77 K and for normal hydrogen at 293 K. These results are collated together in [4916] from which the data shown in figure 1.16(b) were obtained. The data for normal hydrogen in figure 1.16(b) are the most accurate available and comparison with figures 1.16(a) and 1.15 shows that they are in good agreement with the earlier experimental data. The data for para-hydrogen agree to within 0.5 percent with the earlier results of [3659] and [2267].

Gibson [4450] obtained a set of cross sections that led to calculated values of W in agreement within ± 0.7 percent with these experimental results for hydrogen. In view of the experimental accuracy of the data these cross sections which are considerably different from those obtained earlier [181] are the most accurate available to date. In the above series of experiments the variation of drift velocity with gas pressure was also investigated for $6 \times 10^{18} < N < 10^{20}$ cm^{-3} for both normal and para-hydrogen at 77 K and some of the results for normal hydrogen at the higher pressures are given in table 1.14(a). The linear decrease with increasing pressure observed in both normal and para-hydrogen is consistent with the hypothesis [3665] that temporary negative ion formation associated with rotational excitation occurs.

Results of experiments at higher pressures in normal hydrogen at room temperature [3382, 4058] which are shown in table 1.14(b) seem to require a different explanation (as do other results [5103] at 77.8 K over a similar range of values of N) and a multiple scattering theory has been proposed (W. Legler, Phys. Lett. **A29**, 719, 1969) for this range.

In the region above $E/N = 112 \times 10^{-17}$ V cm^2, only one extensive set of data exists. This was obtained by Schlumbohm [1625] from a study of avalanche transit times, and the results are shown in figure 1.18 and table 1.13, which also contain three values obtained by Blevin and Hasan [3459] at the lower end of this range.

3.1.i. Values of W_M—Hydrogen

Creaser [3384] recently obtained values of W_M, with an error of about 1 percent as shown in figure 1.19 and in table 1.15, where they are compared with the early values of Townsend and Bailey [195].

3.1.j. Drift Velocity—Nitrogen

There have been well over thirty experimental investigations of W for nitrogen. It is convenient to consider these in two groups depending on whether the value of E/N used was larger or smaller than about 5.6×10^{-16} V cm^2. For the lower values of E/N, electrical shutter methods first employed by Bradbury and Nielsen [1381] have been widely used [530, 1155, 1381, 2285] and as shown by Lowke [1155] can give results accurate to within 1 percent when appropriate precautions are taken. For the most part, the results obtained at higher values of E/N are from studies of electron pulses and avalanches [1314, 1716, 1763, 2136, 2154].

Those results for $E/N < 5.6 \times 10^{-16}$ V cm^2 which can be expressed as functions of E/N are shown in figure 1.20. (For clarity of presentation, this is given in two parts (a) and (b) with one set of results common to both to aid comparison.) Results in the range $5.6 \times 10^{-16} < E/N < 5.6 \times 10^{-15}$ V cm^2 are shown in figure 1.21 from which it can be seen that there is more scatter in the results in this region than at the lower values of E/N covered by figure 1.20, where there is good agreement between the various sets of data obtained. Numerical values in the two different E/N ranges are given in tables 1.16 and 1.17.

There is only one set of measurements published for $E/N > 5.6 \times 10^{-15}$ V cm^2. These are shown in figure 1.22 and given in table 1.18.

At low values of E/N, the drift velocity is dependent on the temperature and the experimental values of W at the extreme temperatures used both below and above room temperature are shown in figure 1.23 where they are compared with some of the results at room temperature. Values at temperatures of 77 K, 195 K and 473 K are given in table 1.19. Also shown in figure 1.23 are the values calculated [218] on the basis of a numerical solution of the Boltzmann equation and appropriate choice of the collision cross sections involved.

For highly compressed gases at room temperature, Grunberg [3382] has shown that the drift velocity depends not only on E/N but also on N and this dependence is shown in table 1.20. This table also includes the results of Allen and Prew [5188] which also show a significant decrease of W with increasing N at the lower values of E/N used.

3.1.k. Values of W_M—Nitrogen

An extensive investigation of the values of W_M in nitrogen, which extended and substantially confirmed the early work of Townsend and Bailey [195], was recently carried out by Jory [1429]. The results of these experimental investigations are shown in figure 1.24 and in table 1.21.

Values of the magnetic deflection coefficient ψ obtained using the value of W_M shown in figure 1.24 together with the values of W obtained by Lowke [1155], are shown in figure 1.25, where they are compared with the values of ψ obtained theoretically by Englehart, Risk, and Phelps [218] with which there is good agreement.

3.1.l. Drift Velocity—Oxygen

A complication in oxygen and other electronegative gases is the formation of negative ions, with the result that fewer measurements have been made in these gases than in hydrogen and nitrogen.

The majority of the data [727, 1336, 1412, 2553, 5226, 4901] available has been obtained using drift-tube measurements and the results obtained for $2.8\times 10^{-17} < E/N < 57\times 10^{-17}$ V cm^2 are shown in figure 1.26(a). These results include one set [4901] for oxygen containing 2 percent hydrogen in which the dissociative detachment reaction between O^- and H_2 rapidly removes the O^-, so avoiding some of the complications arising from the presence of negative ions. Recently measurements have been extended [5135] to very low values of E/N using the drift-dwell-drift method (see sec. 3.3.a). The values obtained are compared with the earlier drift tube studies, which extend into the region of E/N below 2.8×10^{-17}, in figure 1.26(b). As can be seen from figure 1.26(a) and (b) the self-consistent set of cross sections chosen to give agreement with the earlier drift velocity data and other measured swarm parameters seem to give values of W that are too low at very low values of E/N. Numerical data for the region $E/N < 57\times 10^{-17}$ V cm^2 are given in table 1.22.

For values of $E/N > 57\times 10^{-17}$ V cm^2 most of the experimental data have been obtained from studies of pulsed avalanches [1314, 2370] and these are given in figure 1.27 together with a few experimental results of drift tube measurements [5226] and theoretically computed values [2553] at the lower end of the range. The experimental data in this range are given in table 1.23.

3.1.m. Values of W_M—Oxygen

The only values of W_M available for oxygen are those obtained in the early work of Townsend and Bailey [195] and of Brose [2089] working in the same laboratory. Since the results of Townsend and Bailey show a dependence of W on N as well as on E/N which was removed by the improved techniques used by Brose, only Brose's results are given in figure 1.28 and in table 1.24.

3.1.n. Drift Velocity—Carbon Monoxide

The only data for W for carbon monoxide that can be expressed unambiguously in terms of E/N are those of Pack, Voshall, and Phelps [439] which were obtained for three different temperatures. These are shown in figure 1.29 and table 1.25. The authors state that there is scatter in their data for $T = 300$ K at low values of E/N ($< 8.5\times 10^{-19}$ V cm^2) because of attachment, which did not, however, occur excessively under other conditions.

3.1.o. Values of W_M—Carbon Monoxide

The only values of W_M available for carbon monoxide are those of Skinker [200]. The value of the temperature to which the values of E/p given in the paper correspond is not given and a temperature of 15° C was assumed to obtain the data given in figure 1.30 and table 1.26.

3.1.p. Drift Velocity—Nitric Oxide

The only published values of drift velocities for nitric oxide are the recent results of Parkes and Sugden [4943], obtained using a pulsed drift tube. These are shown in figure 1.31. The results were obtained at temperatures of 294 and 459 K and for a range of values of N from 2.1 to 7.1×10^{17} cm^{-3} but no systematic change with temperature or with gas number density was found within these ranges.

3.1.q. Values of W_M—Nitric Oxide

There have been two experimental investigations of W_M for nitric oxide. Skinker and White [200] reported a variation of W_M with N at a given E/N attributed to the formation of negative ions, but gave a graph of W, E/N which is in fair agreement with later results of Bailey and Somerville [2385] using a method [see 2278] designed to eliminate errors due to the presence of negative ions. Bailey and Somerville's results are given in figure 1.32 and table 1.27.

3.1.r. Drift Velocity—Carbon Dioxide

Several sets of experimental values of W for CO_2 have recently been obtained for values of $E/N < 2.82\times 10^{-16}$ V cm^2 both from studies of electron pulses [725, 1833, 2920, 1184] and by using the electrical shutter method [439, 2141]. The latter method is capable of high accuracy provided adequate consideration is given to possible sources of error. Elford [2041], using this method, obtained results with an estimated error of less than 0.5 percent for values of $E/N < 9.1 \times 10^{-17}$ V cm^2 and of less than 1 percent for $9.1 \times 10^{-17} < E/N < 2.12 \times 10^{-16}$ V cm^2. These results, together with the others obtained for $E/N < 2.82 \times 10^{-16}$ V cm^2, are shown in figure 1.33 in which the theoretical values (calculated [2553] using a self-consistent set of cross sections chosen to give agreement with a range of data on electron swarms) are also given. A set of numerical values is given in table 1.28.

There is a marked dependence of W on pressure in carbon dioxide as shown by the results of Allen and Prew [5188] which are given in figure 1.34. This agrees with the earlier results obtained by Lehning [4203] at $E/N < 2.8 \times 10^{-16}$ V cm^2 for the ratio of the drift velocity at various pressures in the range 8000 to 25,000 Torr to that at 500 Torr. The ratio decreased rapidly throughout the range, becoming less than 1/100 at pressures of 20,000 Torr and above.

There are no published experimental data for W in CO_2 in the range $2.82 \times 10^{-16} < E/N < 10^{-15}$ V cm^2 but there are values in the region above $E/N = 10^{-15}$ V cm^2 obtained by Frommhold [2154] and by Schlumbohm [1314]. Frommhold's values are given in figure 1.35. Schlumbohm does not give his experimental data, but states that they can be represented by the equation $W = 1.58 \times 10^6 \, (E/p_{20})^{0.591}$ for E/p_{20} from 150 to 2000 V cm^{-1} Torr^{-1} and values calculated using this equation are also shown in figure 1.35. The data of figure 1.35 are given numerically in table 1.29.

3.1.s. Values of W_M—Carbon Dioxide

The only experimental values of W_M available for CO_2 are the early results of Skinker [198]. These results are shown in figure 1.36 from which it can be seen that the experimental values are in agreement with the theoretical values of Hake and Phelps (also shown in the figure) up to values of E/N about 4×10^{-16} V cm^2 but become smaller than the theoretical values at higher values of E/N.

3.1.t. Drift Velocity—Air

There have been few measurements of W for air. There are two sets of experimental data available for $E/N < 10^{-16}$ V cm^2, one [3165] based on measurements of electron pulses and the other on the electrical shutter method [1412]. The results are given in figure 1.37 and table 1.30.

The only theoretical values for air are those of Heylen [1447] which were obtained using a Maxwellian energy distribution and an assumed form for the variation of the cross section with energy. These theoretical values for $E/N < 10^{-16}$ V cm^2 are also shown in figure 1.37. (It is not clear from the original paper [1447] to what temperature the values of E/p used correspond. The theoretical values in figure 1.37 have been obtained on the assumption that it is 0 °C.)

For $E/N > 9.9 \times 10^{-17}$ V cm^2 there are also two sets of experimental data available [2305, 2370], both obtained from studies of electron avalanches. These data are shown in figure 1.38 and are given in table 1.31. The available theoretical values [1447] in this region are also shown in figure 1.38, and the theoretical values in the region for which there are no experimental data are included in table 1.31.

3.1.u. Values of W_M—Air

The two sets of experimental data available for W_M for air are shown in figure 1.39 and tabulated in table 1.32.

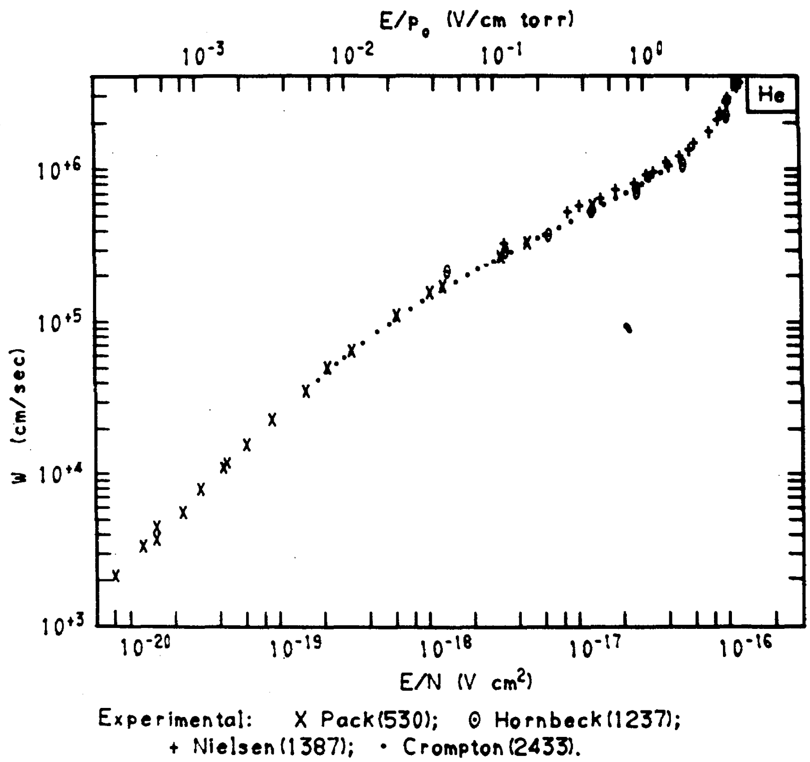


FIGURE 1.1. Experimental values of W as a function of E/N for values of $E/N < 1.3 \times 10^{-16}$ V cm^2 in helium.

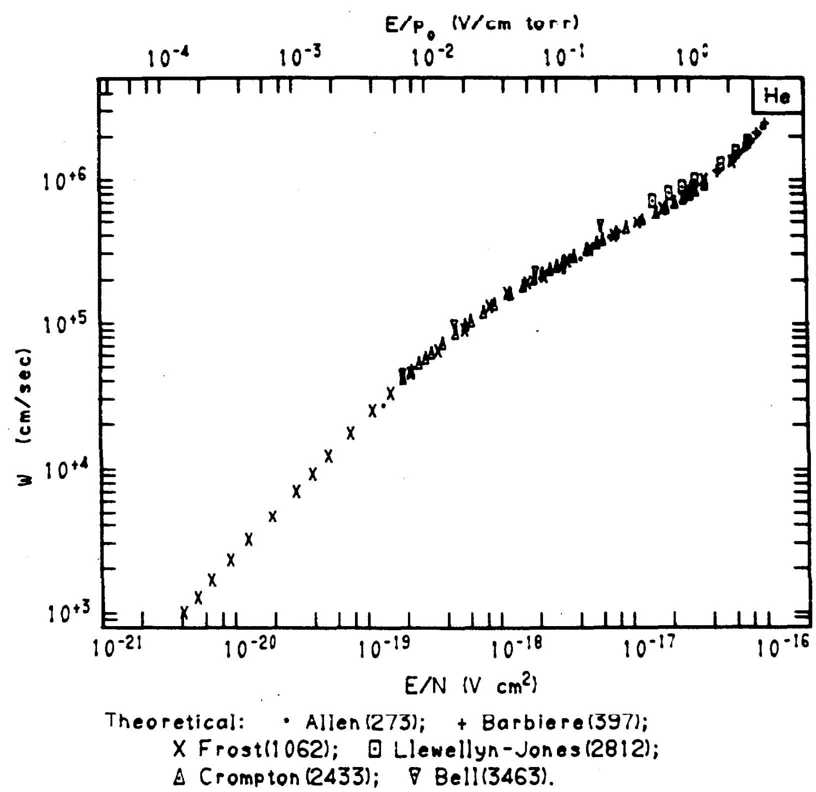


FIGURE 1.2. Theoretically computed values of W as a function of E/N for values of $E/N < 1.3 \times 10^{-16}$ V cm^2 in helium.

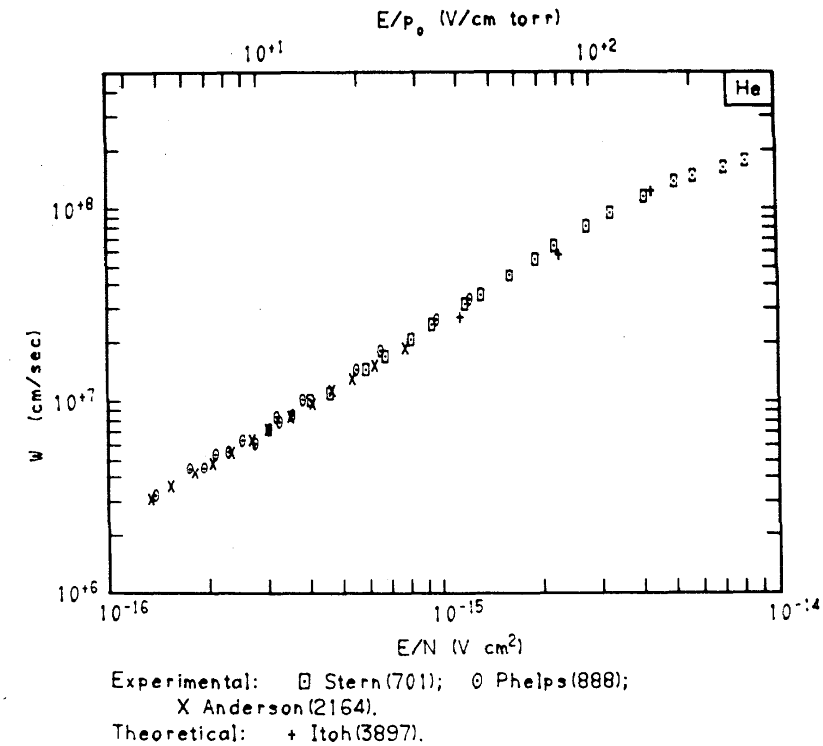


FIGURE 1.3. Experimental values of W for electrons in glow discharges together with computed values for $E/N > 1.3 \times 10^{-16}$ V cm^2 in helium. (Stern's data have been smoothed to avoid a confusing number of points.)

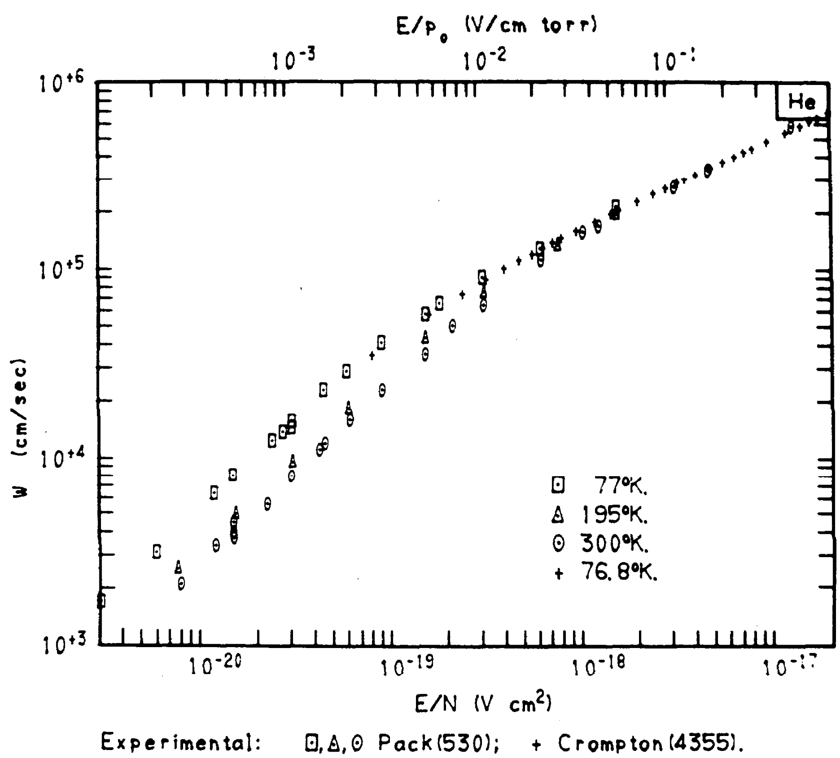


FIGURE 1.4. W as a function of E/N in helium at different temperatures.

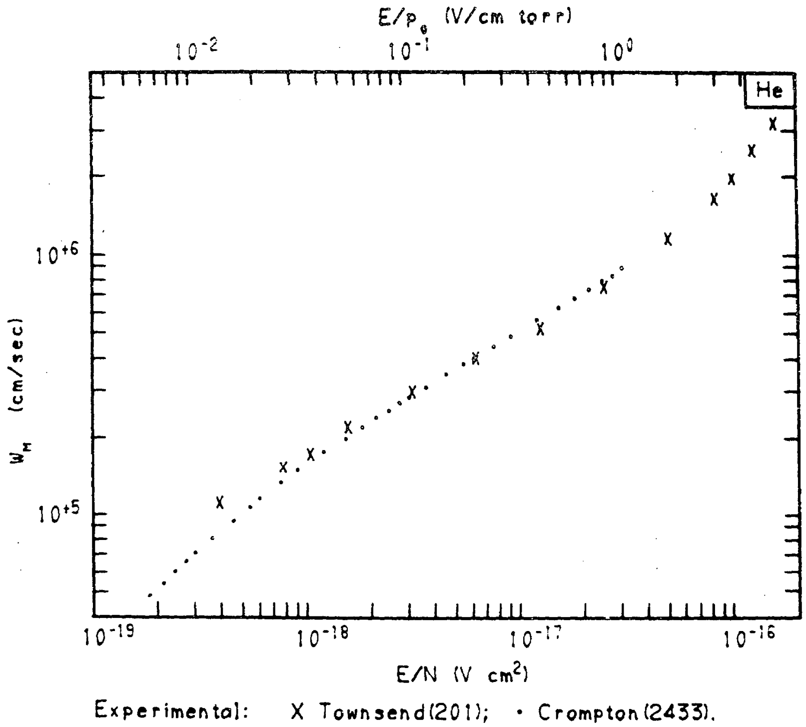


FIGURE 1.5. W_M, E/N for helium.

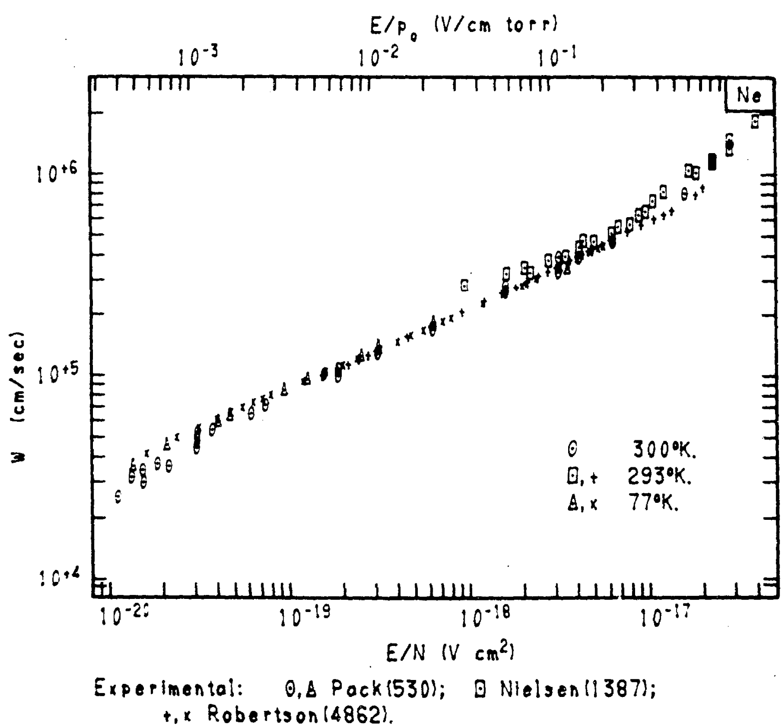
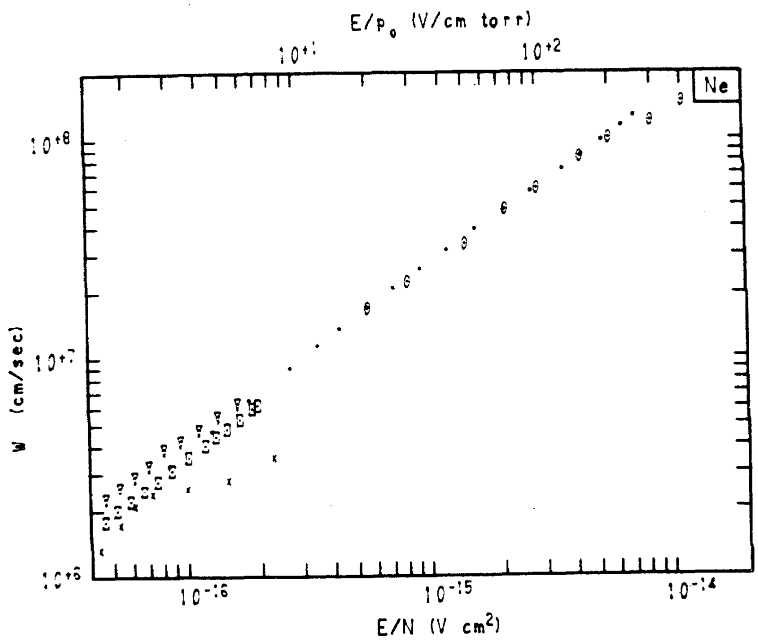
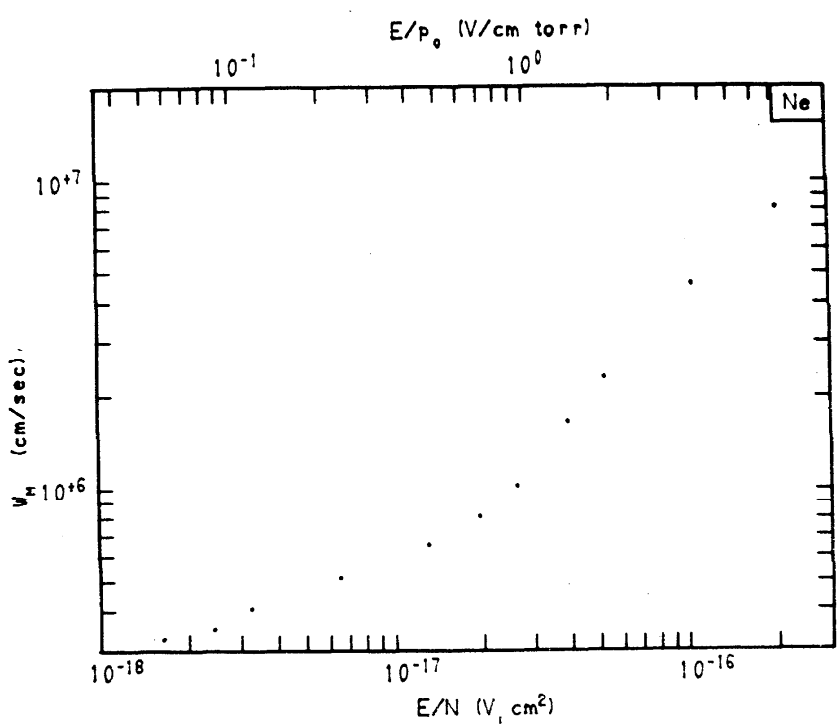


FIGURE 1.6. W, E/N for neon for $E/N < 4 \times 10^{-17}$ V cm^2.



Experimental: ∇ Anderson(2164); ⊟ Takayama (as given in Anderson(2164)); x Sugawara(5780).
Theoretical: ⊙ Thomas(3752); • Thomas(3753)(as given in Thomas(3752)).

FIGURE 1.7. Values of W as a function of E/N for neon for $E/N > 4\times10^{-17}$ V cm^2.



Experimental: Bailey(2280) (Data for Ne+1% He).

FIGURE 1.8. W_M, E/N for neon.

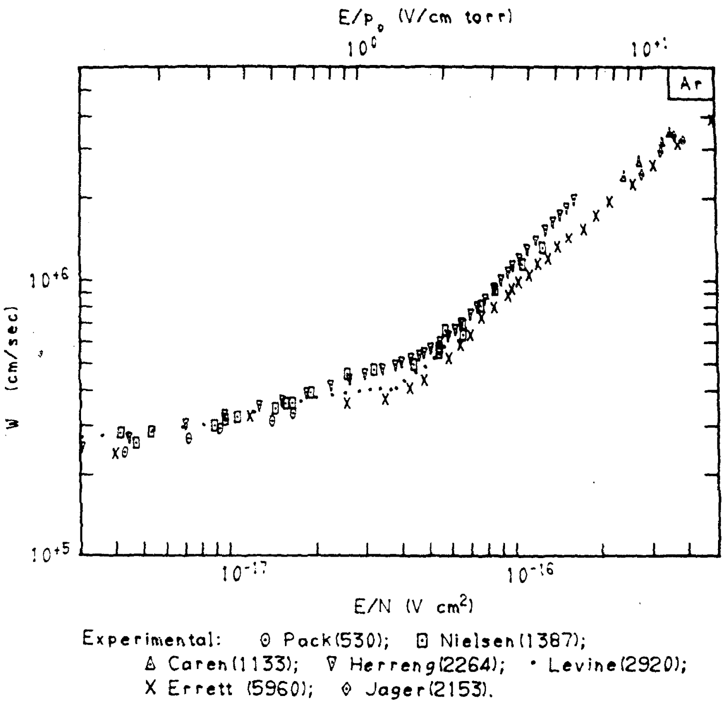


FIGURE 1.9. Experimental values of W as a function of E/N for argon in the range $3\times10^{-18} < E/N < 4\times10^{-16}$ V cm^2.

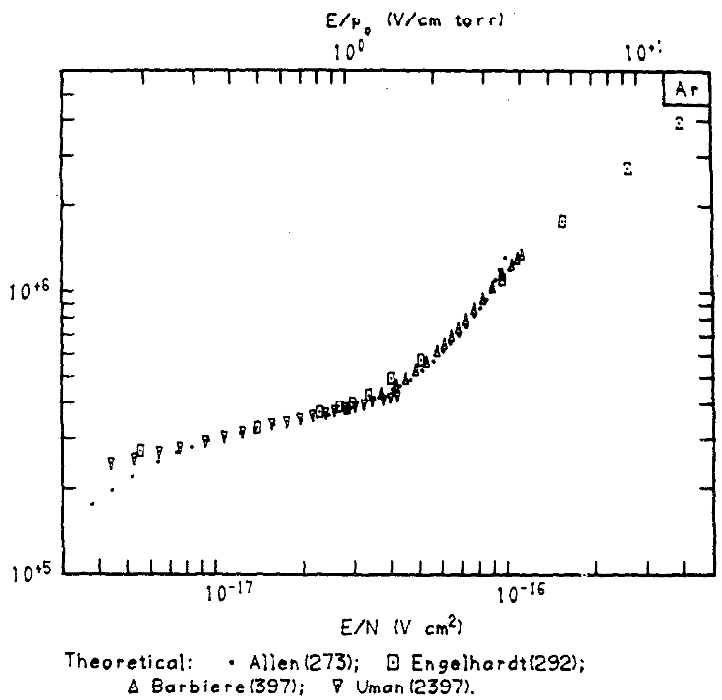
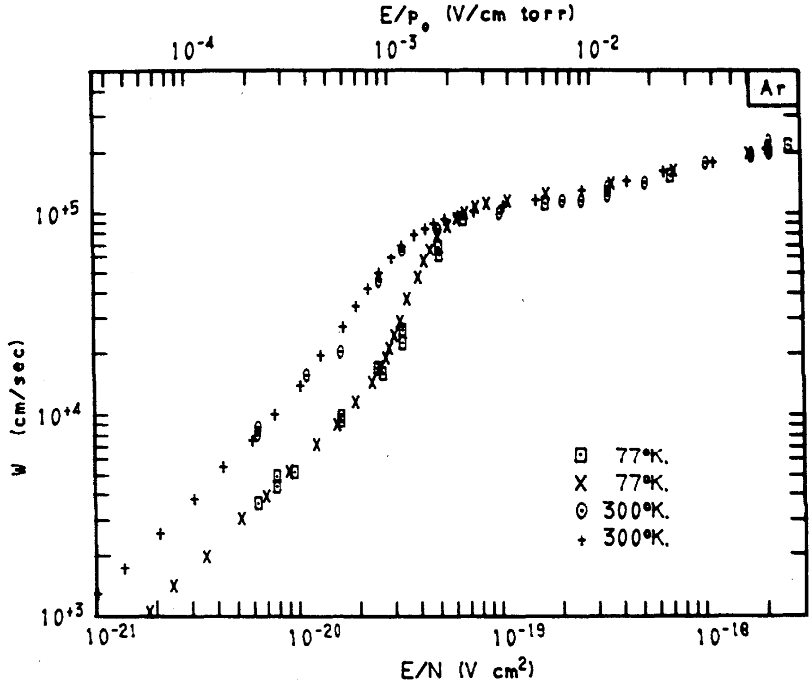
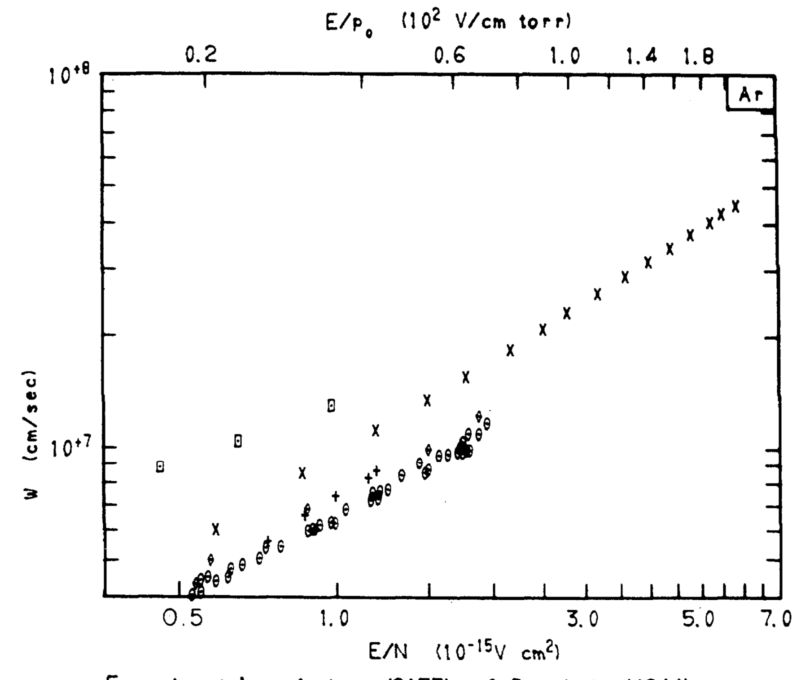


FIGURE 1.10. Theoretical values of W as a function of E/N for argon in the range $3\times10^{-18} < E/N < 4\times10^{-16}$ V cm^2.



Experimental: ⊙,⊡ Pack(530).
Theoretical: +,X Frost(1062).

FIGURE 1.11. W, E/N for argon for $E/N < 3 \times 10^{-18}$ V cm^2.



Experimental: ◊ Jager(2153); ⊙ Brambring(4944); + Wagner(4971).
Theoretical: X Golant(881); ⊡ Engelhardt (292)

FIGURE 1.12. W, E/N for argon for $E/N > 4 \times 10^{-16}$ V cm^2.

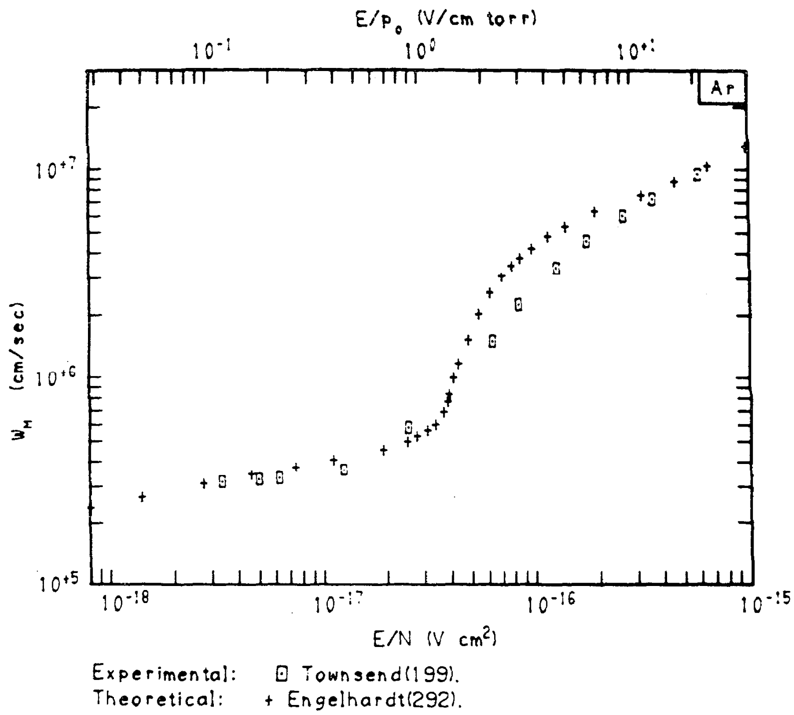


FIGURE 1.13. W_M, E/N for argon.

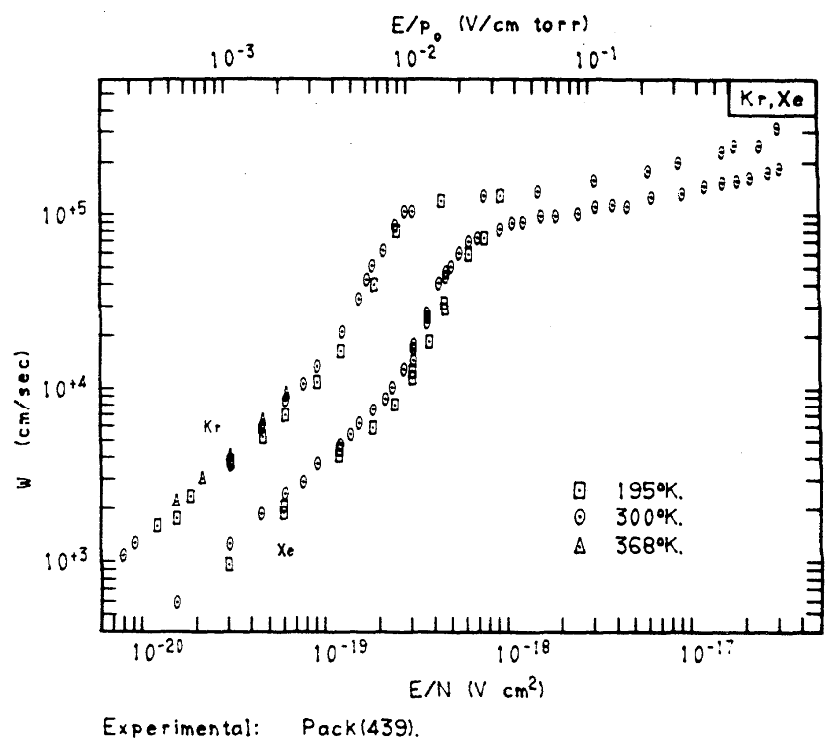


FIGURE 1.14(a). Experimental values of W as a function of E/N for krypton and xenon for $E/N < 4\times 10^{-17}$ V cm^2.

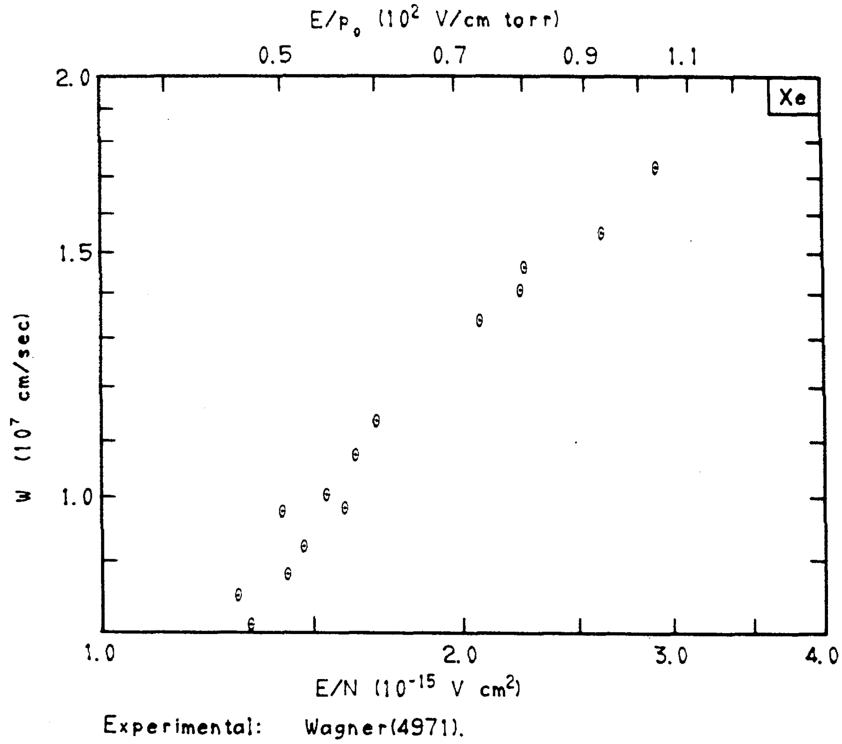


FIGURE 1.14(b). Experimental values of W as a function of E/N for xenon for $E/N > 112 \times 10^{-17}$ V cm^2.

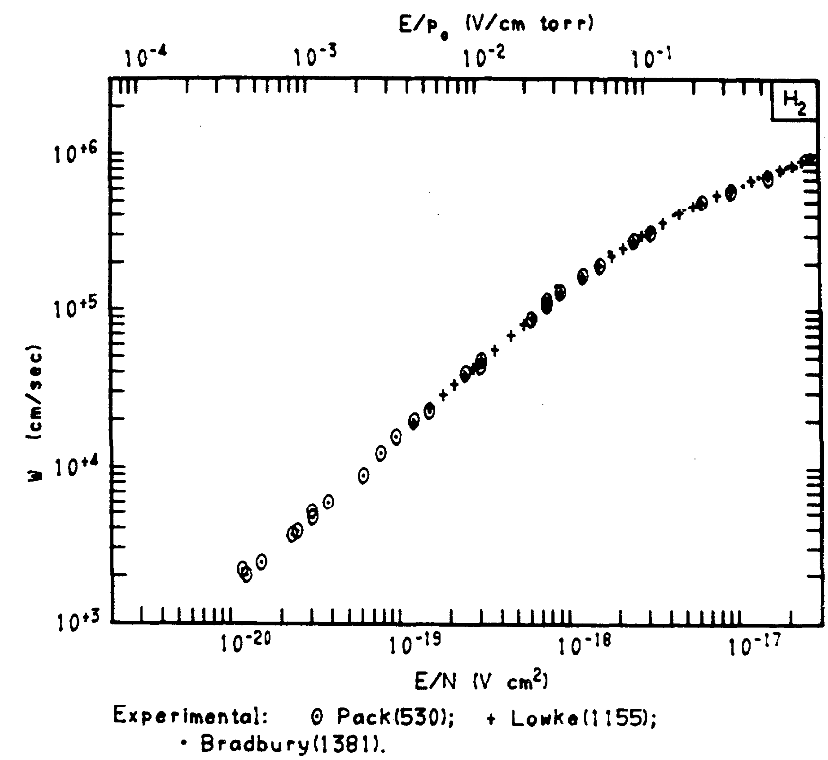
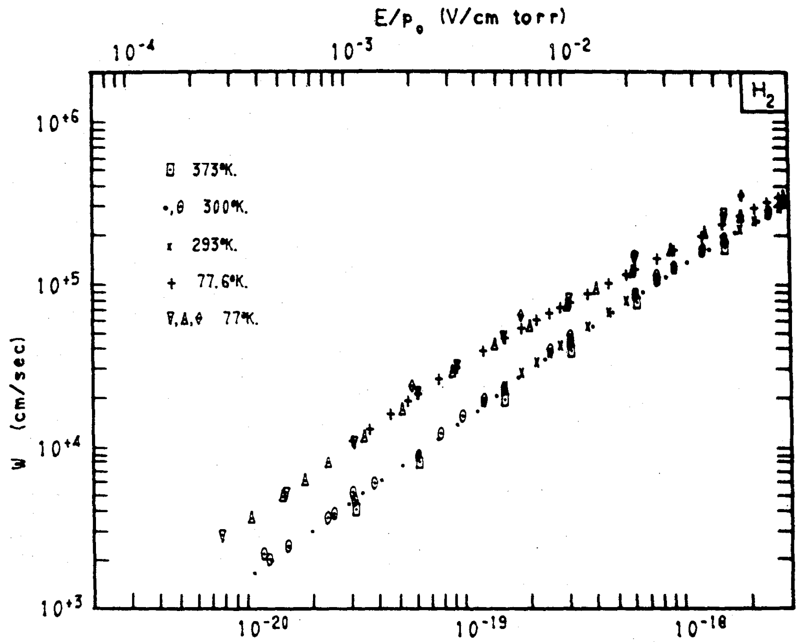
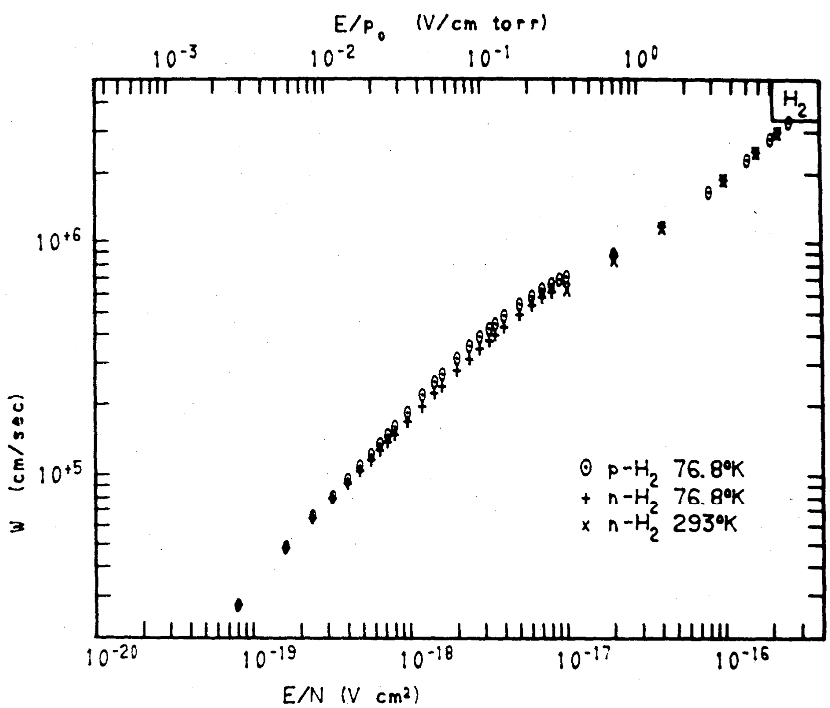


FIGURE 1.15. Experimental values of W as a function of E/N for hydrogen for $E/N < 2.82 \times 10^{-17}$ V cm^2.



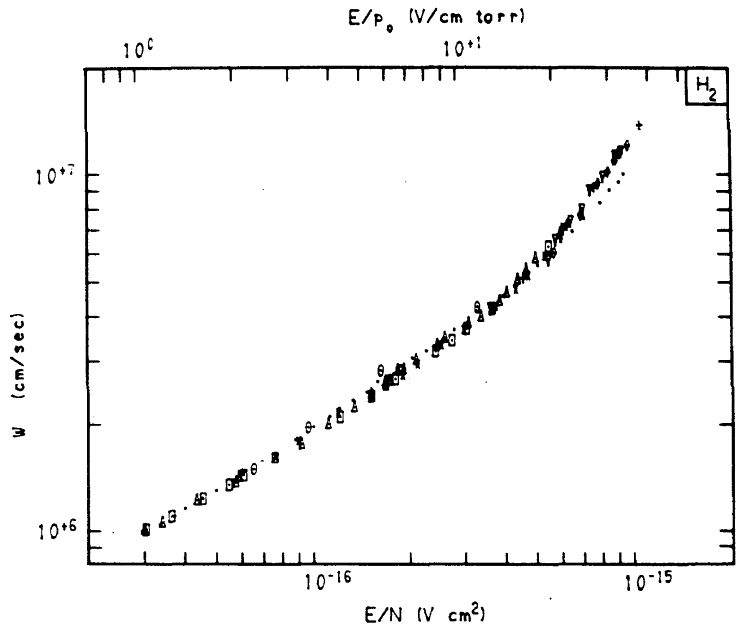
Experimental: ∇,Θ,⊡ Pack(530); x,+ Lowke(1155).
Theoretical: •,Δ Frost(181); ◊ Bell(3463).

FIGURE 1.16(a). *W*, *E/N* for hydrogen for various temperatures at low values of *E/N*.



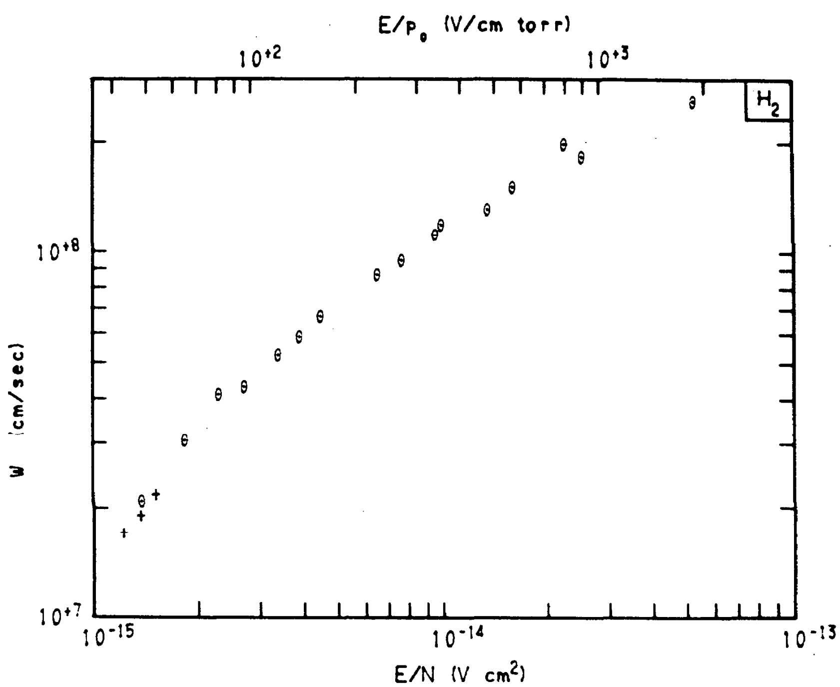
Experimental: Robertson(4916)

FIGURE 1.16(b). Experimental values of *W* in para-hydrogen at 76.8 K and normal hydrogen at 76.8 and 293 K.



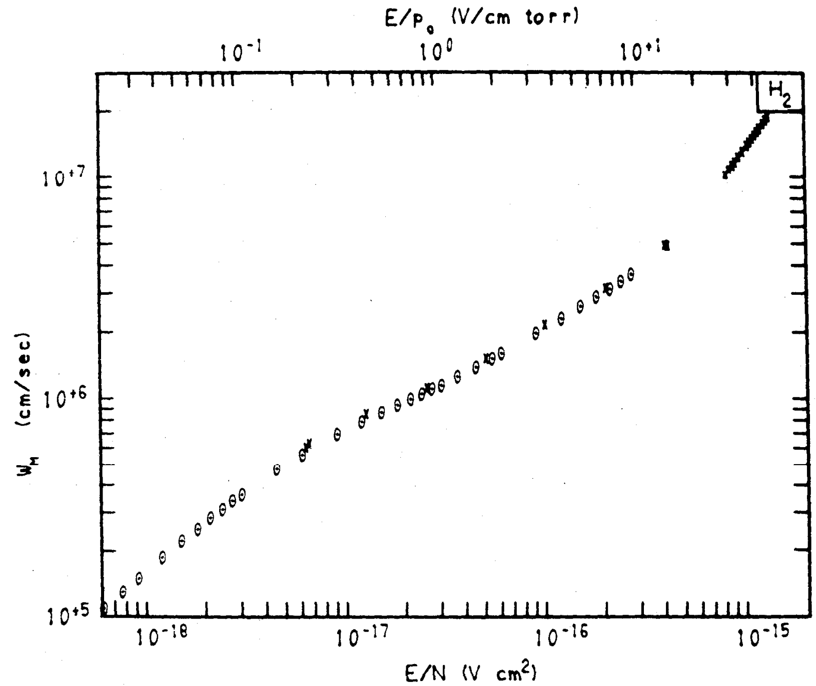
Experimental: ⊙ Pack(530); ⊡ Lowke(1155);
Δ Bradbury(1381); ∇ Jager(2153); ◇ Frommhold(2154);
x Prasad(2285); + Blevin(3459).
Theoretical: • Frost(181).

FIGURE 1.17. W, E/N for hydrogen in the range $2.8\times10^{-17} < E/N < 113\times10^{-17}$ V cm².



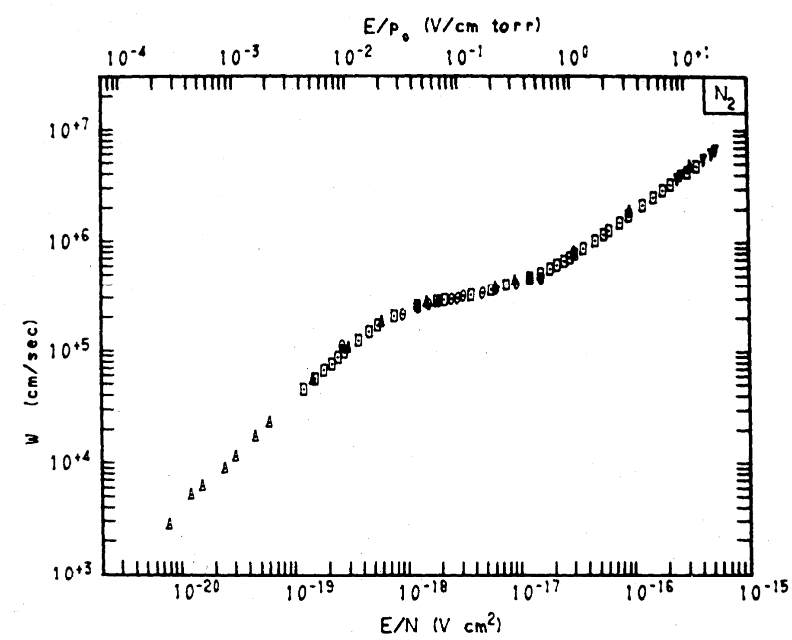
Experimental: ⊙ Schlumbohm(1314); + Blevin(3459).

FIGURE 1.18. W, E/N for hydrogen for $E/N > 112\times10^{-17}$ V cm².



Experimental: ⊙ Creaser(3384); x Townsend(195).

FIGURE 1.19. Experimental W_M, E/N for hydrogen.



Experimental: ∆ Pack(530); ⊙ Christophorou(725); ⊡ Lowke(1155); ∇ Prasad(2285).

FIGURE 1.20(a). Experimental values of W as a function of E/N for nitrogen for $E/N < 5.6 \times 10^{-16}$ V cm^2.

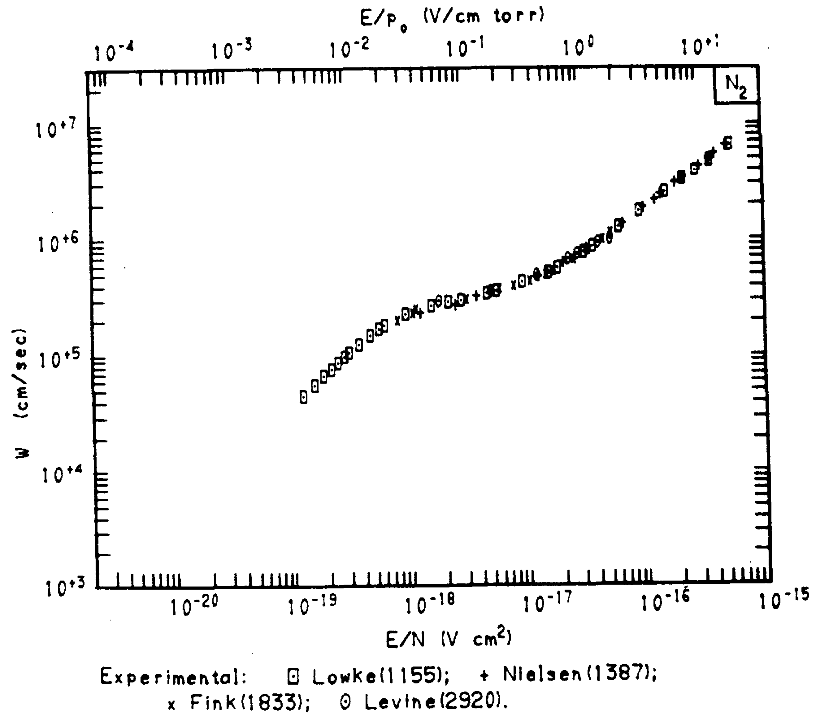


FIGURE 1.20(b). Experimental values of W as a function of E/N for nitrogen for $E/N < 5.6 \times 10^{-16}$ V cm^2.

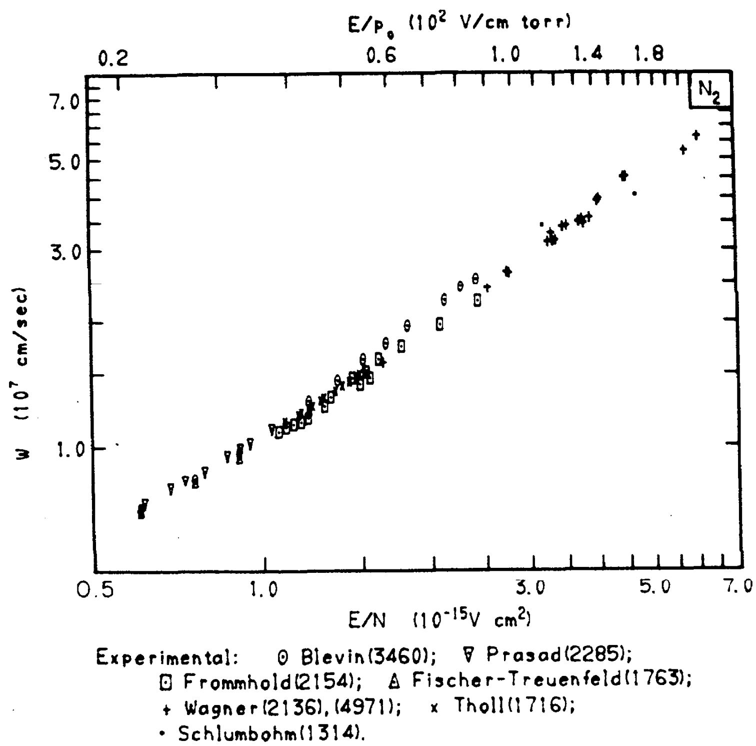


FIGURE 1.21. Experimental values of W as a function of E/N for nitrogen for $5.6 \times 10^{-16} < E/N < 6.2 \times 10^{-15}$ V cm^2.

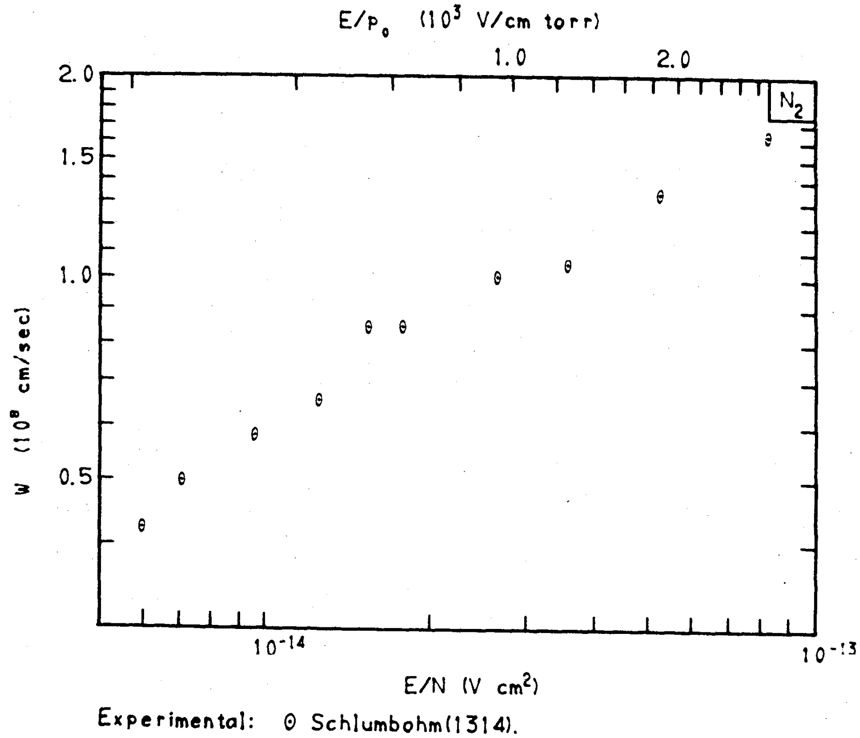


FIGURE 1.22. Experimental values of W as a function of E/N for nitrogen for $E/N > 5.6 \times 10^{-15}$ V cm².

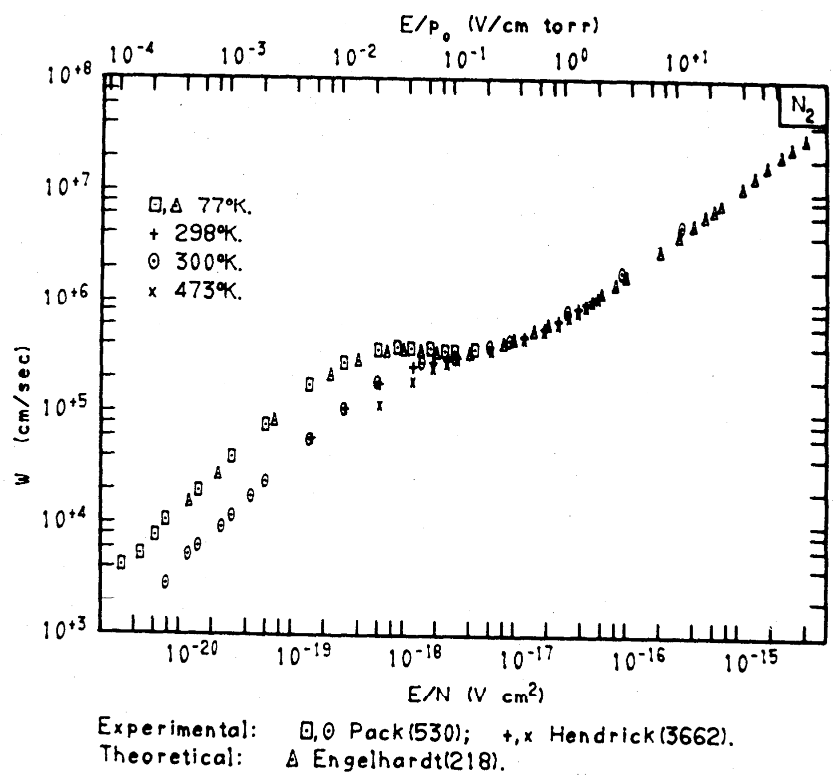
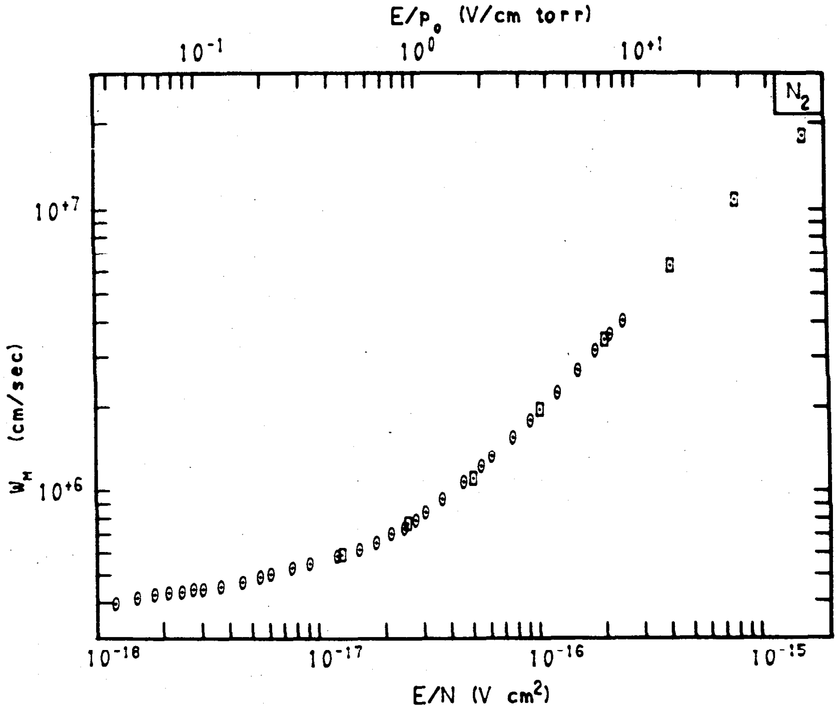
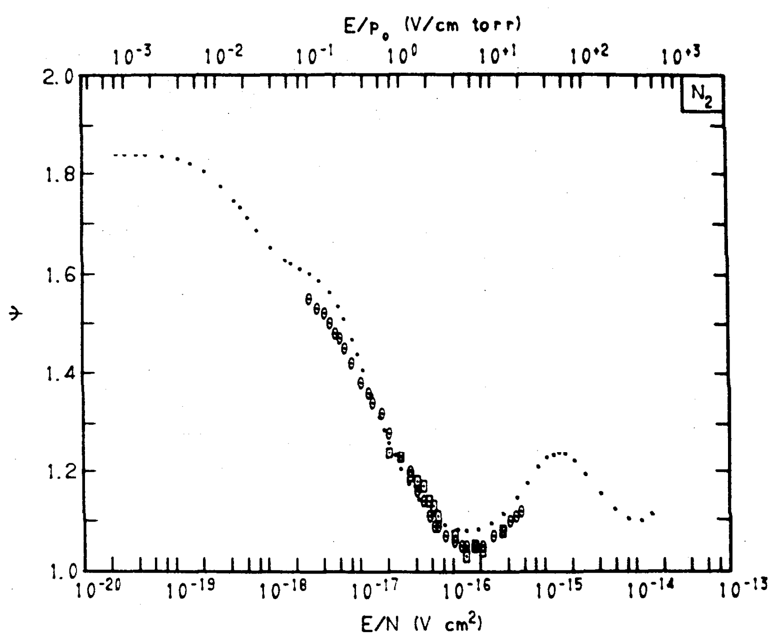


FIGURE 1.23. Values of W as a function of E/N for nitrogen at various temperatures.



Experimental: ⊖ Jory(1429); ⊡ Townsend(195).

FIGURE 1.24. Experimental values of W_M as a function of E/N for nitrogen.



Experimental: ⊖ Using W_M from Jory(1429) and W from Lowke(1155); ⊡ Using W_M from Townsend(195) and W from Lowke(1155).

Theoretical: • Engelhardt(218).

FIGURE 1.25. Values of ψ as a function of E/N for nitrogen.

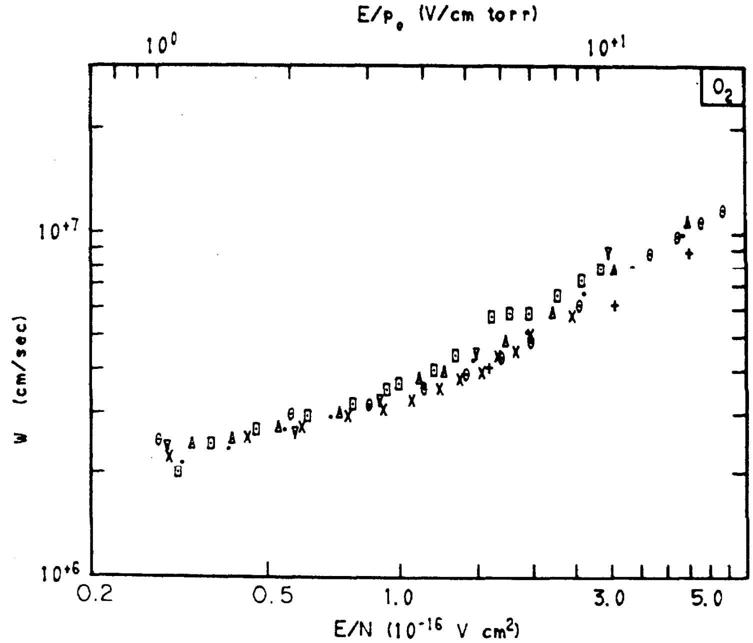


FIGURE 1.26(a). W, E/N for oxygen for $2.8\times10^{-17} < E/N < 57\times10^{-17}$ V cm^2.

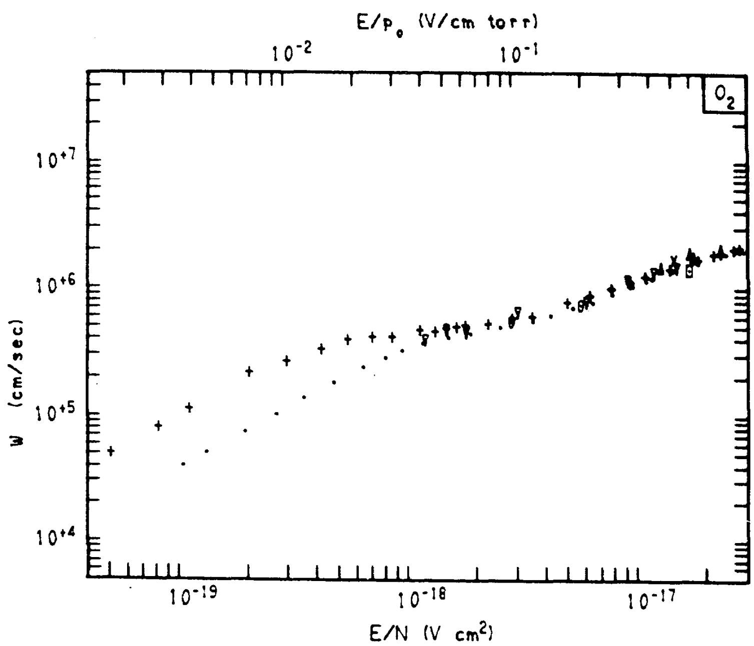
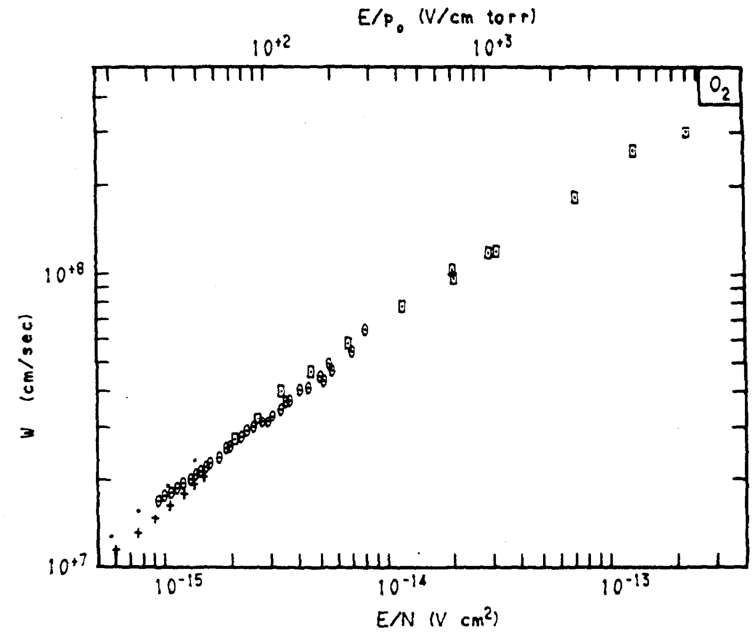
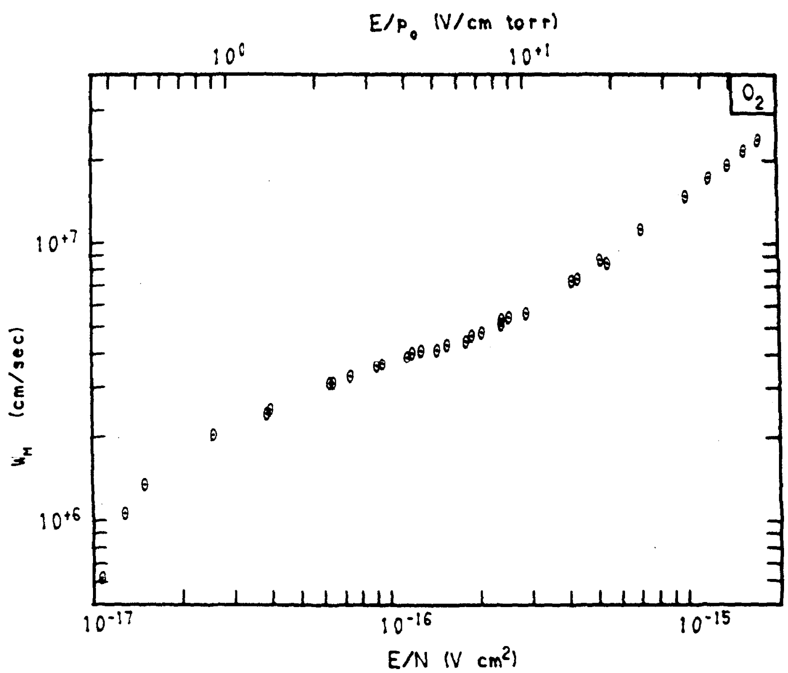


FIGURE 1.26(b). W, E/N for oxygen for $E/N < 2.8\times10^{-17}$ V cm^2.



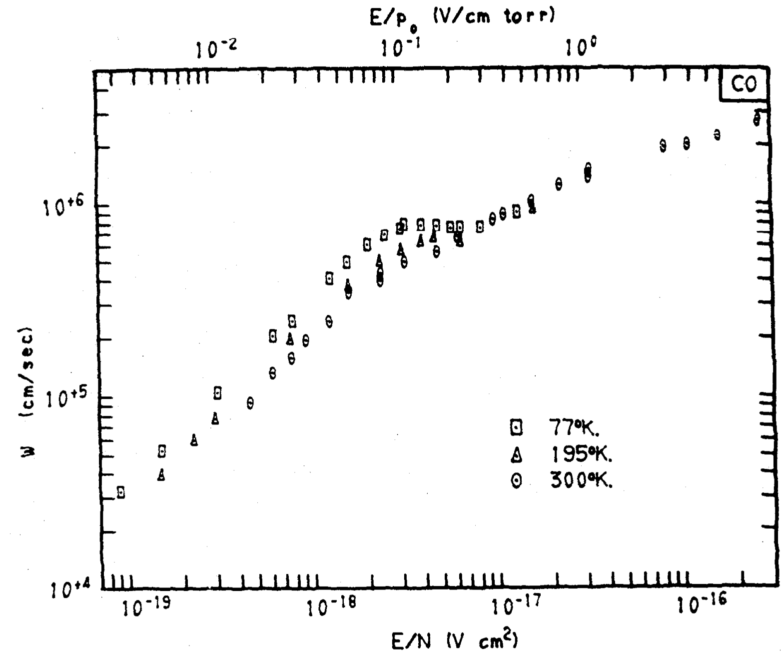
Experimental: ⊖ Frommhold(2370); ⊡ Schlumbohm(1314);
+ Naidu(5226).
Theoretical: • Hake(2553).

FIGURE 1.27. W, E/N for oxygen for $E/N > 5.7 \times 10^{-16}$ V cm^2.



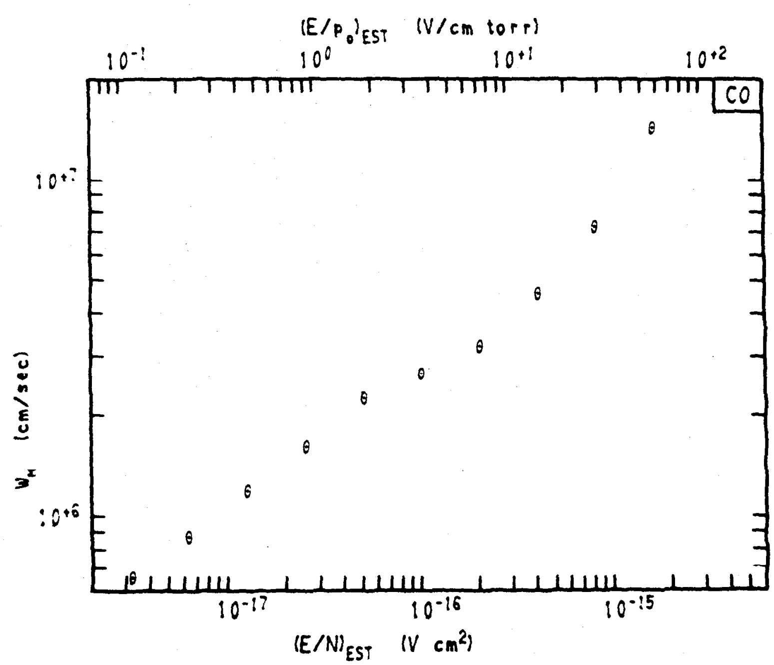
Experimental: ⊖ Brose(2089).

FIGURE 1.28. Experimental values of W_M, E/N for oxygen.



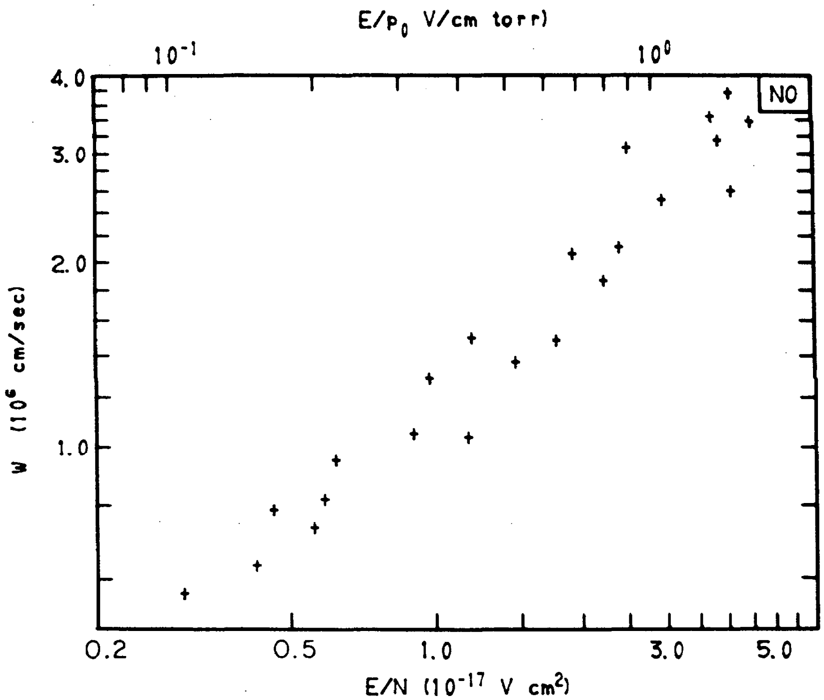
Experimental: Pack(439).

FIGURE 1.29. Experimental W, E/N for carbon monoxide.



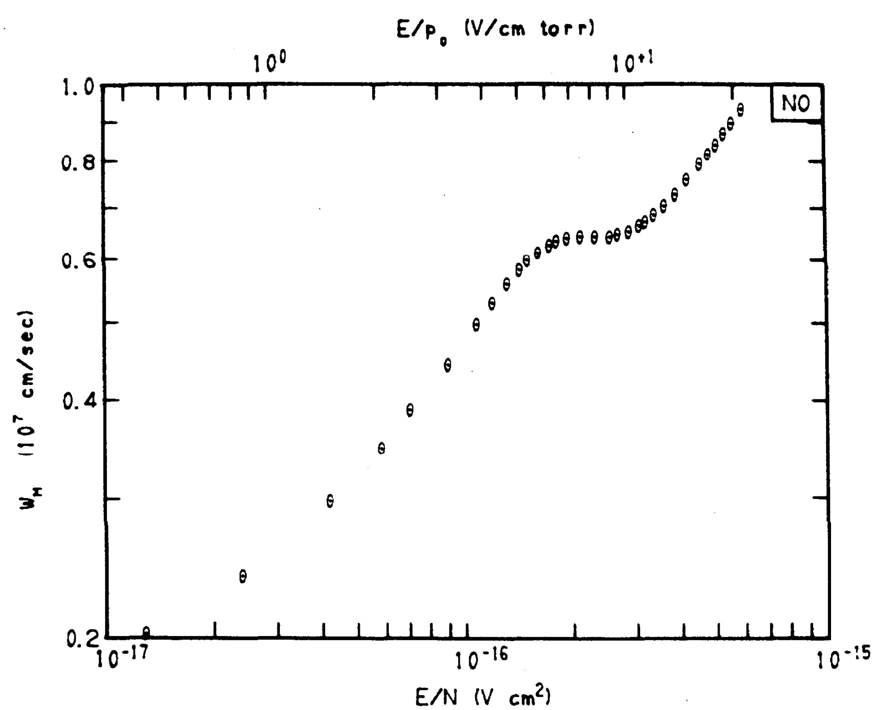
Experimental: ⊖ Skinker(200).

FIGURE 1.30. Experimental W_M, $(E/N)_{Est}$ for carbon monoxide.



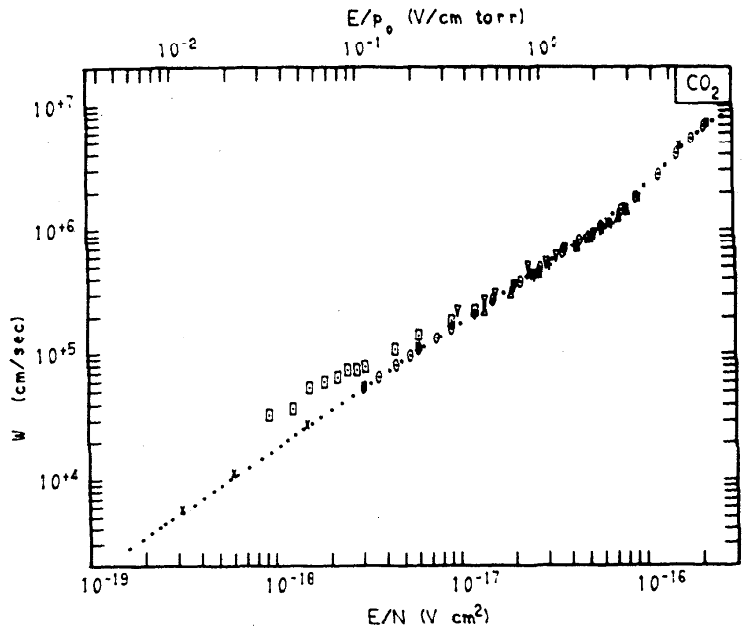
Experimental: Parkes(4943).

FIGURE 1.31. Experimental W, E/N for nitric oxide.



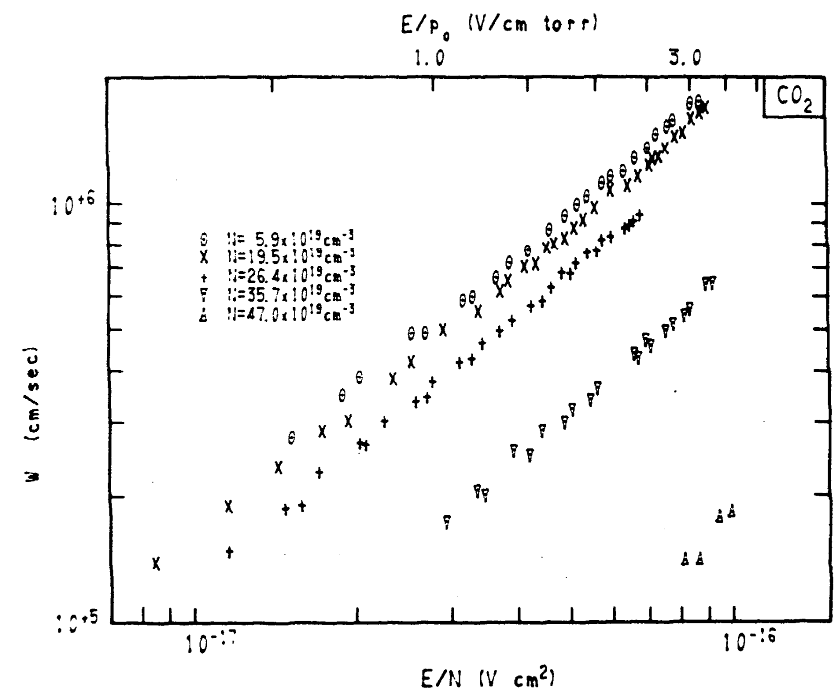
Experimental: ⊖ Bailey(2385).

FIGURE 1.32. Experimental W_M, E/N for nitric oxide.



Experimental: ⊖ Elford(2041); ⊟ Christophorou(725); Δ Fink(1833); ∇ Levine(2920); + Hurst(1184); x Pack(439).
Theoretical: Hake(2553).

FIGURE 1.33. W, E/N for carbon dioxide for $E/N < 2.82 \times 10^{-16}$ V cm^2.



Experimental: all data from Allen(5188).

FIGURE 1.34. Variation of W with gas number density for carbon dioxide.

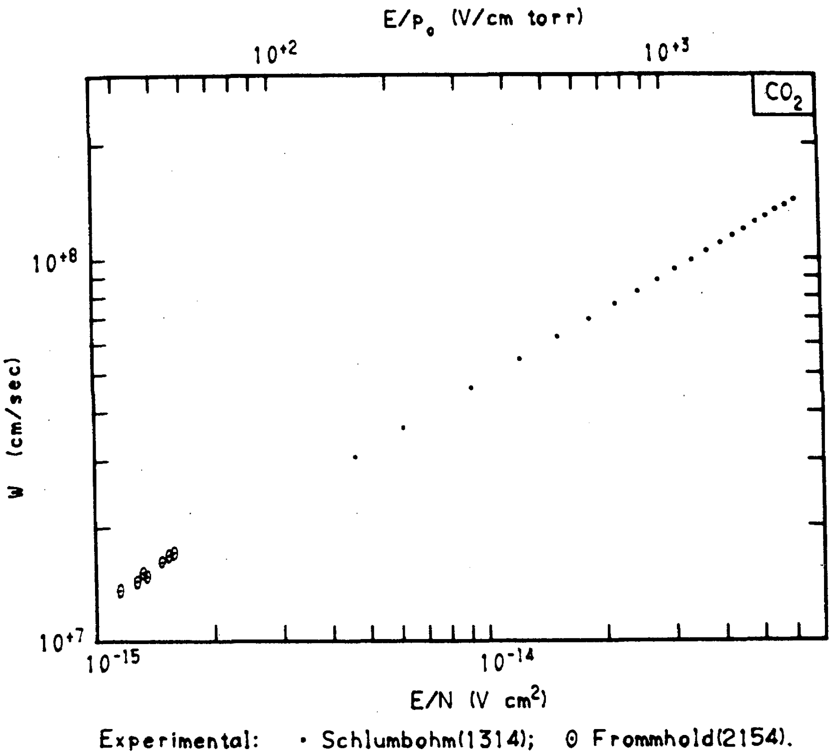


FIGURE 1.35. Experimental W, E/N for carbon dioxide for $E/N > 10^{-15}$ V cm^2.

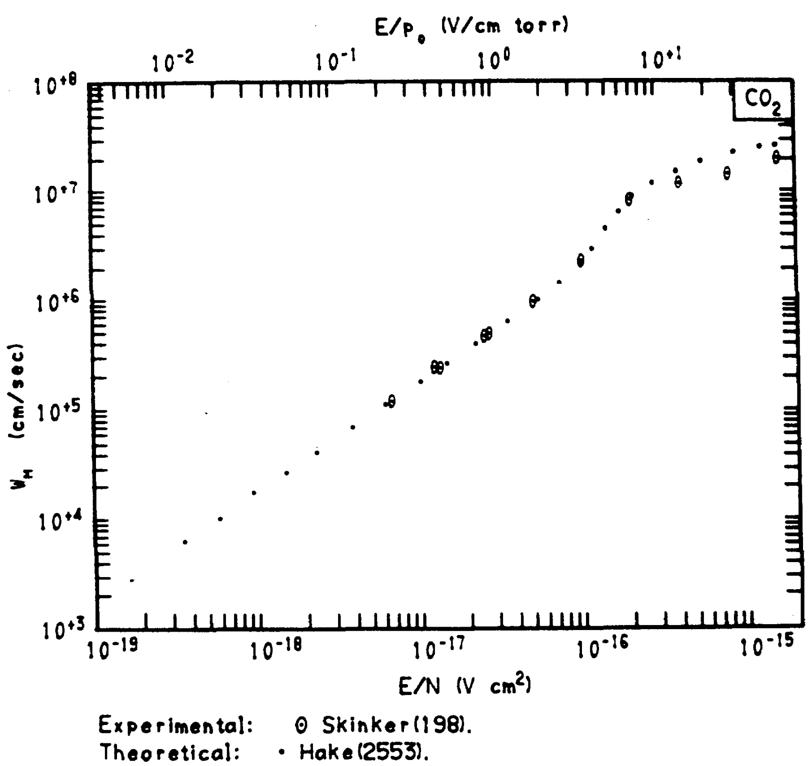
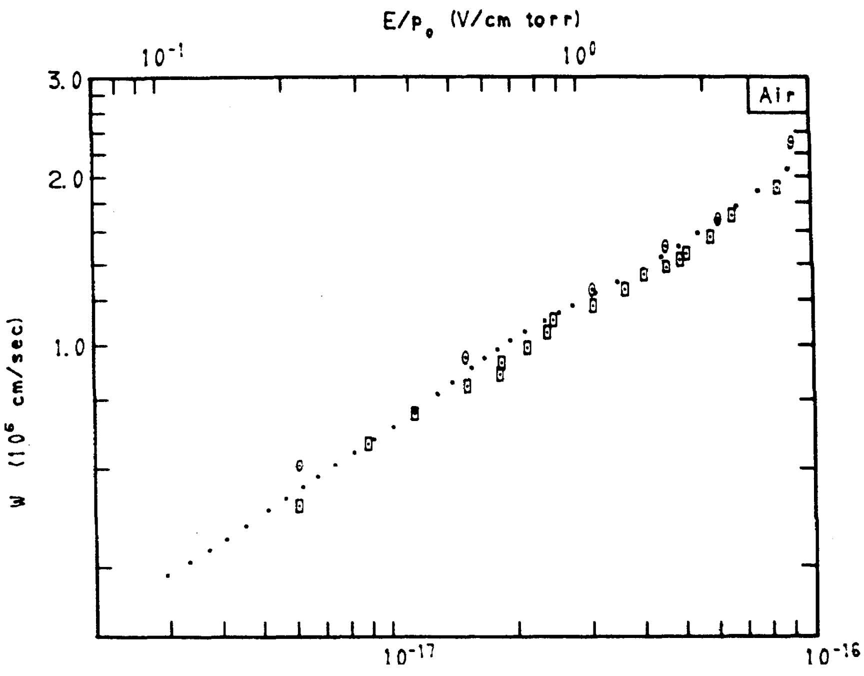
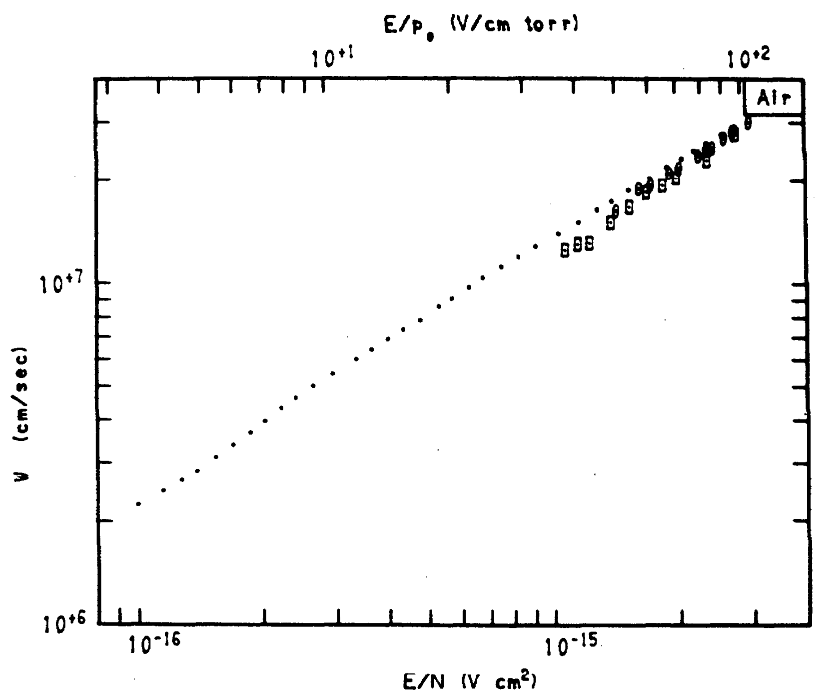


FIGURE 1.36. W_M, E/N for carbon dioxide.



Experimental: ⊙ Hessenauer(3165); ⊡ Nielsen(1412).
Theoretical: • Heylen(1447).

FIGURE 1.37. W, E/N for air for $E/N < 9.87 \times 10^{-17}$ V cm^2.



Experimental: ⊙ Ryzko(2305); ⊡ Frommhold(2370).
Theoretical: • Heylen(1447).

FIGURE 1.38. W, E/N for air for $E/N > 9.87 \times 10^{-17}$ V cm^2.

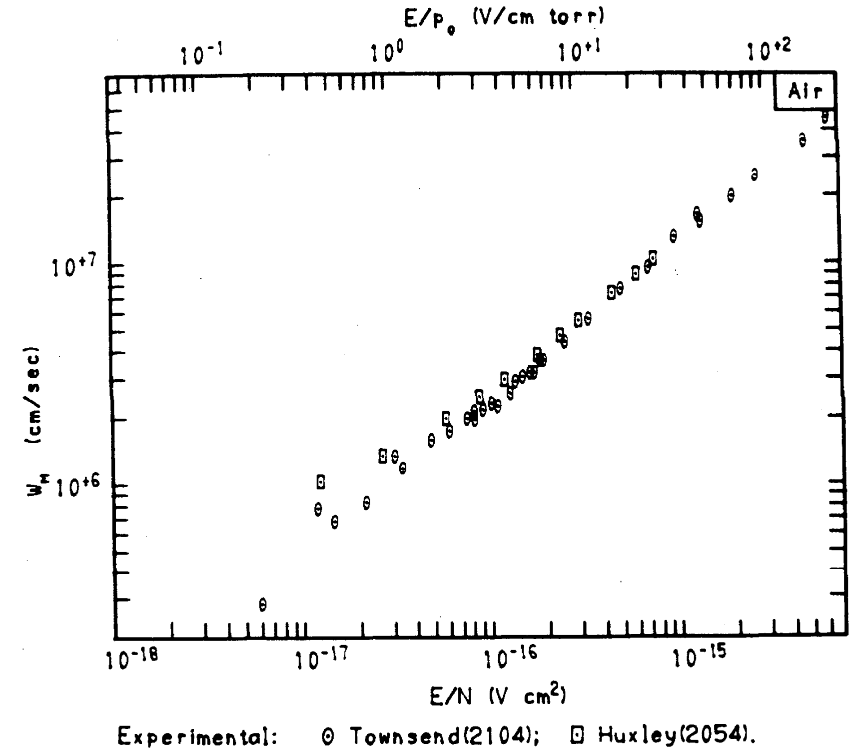


Figure 1.39. Experimental W_M, E/N for air.

Table 1.1(a)

Values of W for helium for $E/N < 4 \times 10^{-17} Vcm^2$ at ambient temperature

E/N ($10^{-17} Vcm^2$)	W (10^5 cm/sec)	E/N ($10^{-17} Vcm^2$)	W (10^5 cm/sec)	E/N ($10^{-17} Vcm^2$)	W (10^5 cm/sec)
0.000795	0.0210 (a)	0.02730	0.586 (b)	0.364	2.93 (b)
0.001219	0.034 (a)	0.0303	0.637 (b)	0.455	3.28 (b)
	0.037 (a)	0.0364	0.733 (b)	0.546	3.60 (b)
0.001518	0.045 (a)	0.0455	0.863 (b)	0.607	3.79 (b)
	0.040 (a)	0.0546	0.980 (b)	0.759	4.23 (b)
0.002281	0.056 (a)	0.0607	1.052 (b)	0.910	4.63 (b)
0.00303	0.080 (a)	0.0759	1.22 (b)	1.214	5.33 (b)
0.00427	0.111 (a)	0.0910	1.37 (b)	1.517	5.97 (b)
0.00455	0.121 (a)	0.1214	1.62 (b)	1.820	6.55 (b)
0.00609	0.161 (a)	0.1517	1.84 (b)	2.124	7.07 (b)
0.00905	0.230 (a)	0.1820	2.04 (b)	2.430	7.57 (b)
0.01526	0.36 (a)	0.2124	2.21 (b)	2.730	8.07 (b)
0.01820	0.418 (b)	0.2430	2.37 (b)	3.03	8.57 (b)
0.02124	0.477 (b)	0.2730	2.53 (b)	3.64	9.47 (b)
0.02430	0.533 (b)	0.303	2.67 (b)		

Experimental:
(a) Pack, et al., Phys. Rev. 121, 798 (1961).
(b) Crompton, et al., Austr. J. Phys. 20, 369 (1967).

Table 1.1(b)

Values of W for helium showing the variation of W with N at high values of N at ambient temperature

$N(cm^{-3})$	1.074×10^{21}	7.892×10^{20}	5.732×10^{20}	2.783×10^{20}
E/N ($10^{-17} Vcm^2$)	W (10^4 cm/sec)			
.00909	2.03	2.08	2.12	2.19
.0121	2.66	2.74	2.78	2.91
.0151	3.3	3.4	3.4	3.6
.0182	3.9	4.0	4.1	4.2
.0242	5.1	5.2	5.3	5.4
.0303	6.2	6.2	6.3	6.4
.0455	8.6	8.6	8.7	8.7
.0606	10.5	10.6	10.6	10.6

Experimental:
All data taken from Grunberg, Z. Naturforsch. 24a, 1838 (1969).

Table 1.1(c)

Values of W for helium at 77°K

E/N (10^{-17}Vcm^2)	W (10^5cm/sec)		E/N (10^{-17}Vcm^2)	W (10^5cm/sec)		E/N (10^{-17}Vcm^2)	W (10^5cm/sec)	
.000277	.0168	(a)	.0278	.91	(a)	.278	2.67	(b)
.000545	.031	(a)	.0318	.874	(b)	.318	2.84	(b)
.00110	.065	(a)	.0398	.991	(b)	.350	2.97	(b)
.00136	.081	(a)	.0477	1.10	(b)	.398	3.16	(b)
.00218	.124	(a)	.0557	1.19	(b)	.477	3.45	(b)
.00247	.138	(a)	.0559	1.29	(a)	.557	3.71	(b)
.00275	.146	(a)	.0636	1.28	(b)	.636	3.96	(b)
.00275	.157	(a)	.0716	1.36	(b)	.716	4.19	(b)
.00410	.230	(a)	.0795	1.44	(b)	.795	4.40	(b)
.00540	.290	(a)	.0954	1.56	(b)	.954	4.80	(b)
.00795	.345	(b)	.119	1.76	(b)	1.19	5.34	(b)
.00814	.41	(a)	.140	2.13	(a)	1.43	5.85	(b)
.0138	.59	(a)	.143	1.93	(a)	1.59	6.16	(b)
.0159	.570	(b)	.159	2.03	(a)	1.75	6.46	(b)
.0165	.66	(a)	.199	2.27	(a)	1.99	6.89	(b)
.0239	.737	(b)	.239	2.47	(a)			

Experimental:
(a) Pack, et al., Phys. Rev. 121, 798 (1961).
(b) Crompton, et al., Austr. J. Phys. 20, 369 (1967).

Table 1.2

Values of W for electrons in helium glow discharges for E/N > 13 × 10^{-17}Vcm^2 at ambient temperatures

E/N (10^{-17}Vcm^2)	W (10^8cm/sec)		E/N (10^{-17}Vcm^2)	W (10^8cm/sec)		E/N (10^{-17}Vcm^2)	W (10^8cm/sec)	
13.40	0.031	(a)	32.4	0.079	(b)	93.6	0.246	(c)
13.74	0.032	(b)	35.0	0.084	(a)	96.4	0.262	(b)
15.40	0.036	(a)	35.4	0.085	(b)	117.2	0.31	(c)
17.44	0.046	(b)	38.0	0.102	(b)	121.5	0.33	(b)
18.17	0.043	(a)	40.0	0.101	(c)	130.5	0.35	(c)
19.34	0.046	(b)	40.7	0.097	(a)	160.5	0.44	(c)
20.60	0.048	(a)	46.2	0.110	(c)	192.4	0.54	(c)
20.94	0.054	(b)	46.8	0.113	(a)	218.9	0.64	(c)
22.86	0.055	(b)	53.8	0.131	(a)	272.8	0.81	(c)
23.36	0.055	(a)	55.3	0.146	(b)	323	0.95	(c)
25.15	0.064	(b)	59.0	0.146	(c)	407	1.15	(c)
26.84	0.064	(a)	63.0	0.153	(a)	503	1.37	(c)
27.44	0.061	(b)	65.3	0.182	(b)	573	1.47	(c)
30.0	0.072	(a)	67.5	0.170	(c)	704	1.63	(c)
30.2	0.072	(b)	77.4	0.187	(a)	823	1.75	(c)
31.7	0.084	(b)	80.5	0.208	(c)			

Experimental:
(a) Anderson, Phys. Fluids 7, 1517 (1964).
(b) Phelps, et al., Phys. Rev. 117, 470 (1960).
(c) Stern. in Proceedings of the Sixth International Conference on Ionization Phenomena in Gases (Paris, 8-13 July 1963) P. Hubert and E Cremieu-Alcan, eds. (Serma, Paris, 1963), Vol. 1, p. 331.

Table 1.3

Values of W_M for helium

E/N (10^{-17}Vcm^2)	W_M (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W_M (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W_M (10^5cm/sec)
0.01820	0.480 (a) 0.486 (1)	0.1214	1.77 (a) 1.77 (1)	0.607	4.00 (a) 4.08 (1)
0.02124	0.542 (a) 0.551 (1)	0.1517	1.98 (a) 2.01 (1)	0.759	4.45 (a) 4.55 (1)
0.0243	0.602 (a) 0.613 (1)	0.1820	2.19 (a) 2.21 (1)	0.910	4.86 (a) 4.98 (1)
0.0273	0.660 (a) 0.671 (1)	0.2124	2.37 (a) 2.40 (1)	1.214	5.61 (a) 5.73 (1)
0.0303	0.715 (a) 0.727 (1)	0.243	2.53 (a) 2.58 (1)	1.517	6.24 (a) 6.38 (1)
0.0364	0.812 (a) 0.830 (1)	0.273	2.71 (a) 2.74 (1)	1.820	6.80 (a) 6.98 (1)
0.0455	0.947 (a) 0.970 (1)	0.303	2.84 (a) 2.89 (1)	2.124	7.32 (a) 7.53 (1)
0.0546	1.07 (a) 1.10 (1)	0.364	3.11 (a) 3.17 (1)	2.43	7.92 (a) 8.05 (1)
0.0607	1.15 (a) 1.17 (1)	0.455	3.49 (a) 3.54 (1)	2.73	8.31 (a) 8.55 (1)
0.0759	1.33 (a) 1.35 (1)	0.546	3.82 (a) 3.88 (1)	3.03	8.91 (a) 9.03 (1)
0.0910	1.48 (a) 1.50 (1)				

Experimental:
(a) Crompton, et al., Austr. J. Phys. 20, 369 (1967).

Theoretical:
(1) Crompton, et al., Austr. J. Phys. 20, 369 (1967).

Table 1.4(a)

Values of W for neon at ambient temperatures

E/N (10^{-17}Vcm^2)	W (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W (10^5cm/sec)
0.001107	0.251 (a)	0.02732	1.24 (b)	0.486	4.2 (b)
0.001318	0.32 (a)	0.0304	1.30 (b)	0.546	4.5 (b)
0.001538	0.34 (a)	0.0455	1.53 (b)	0.607	4.7 (b)
0.001556	0.30 (a)	0.0607	1.72 (b)	0.759	5.2 (b)
0.001854	0.37 (a)	0.0911	2.04 (b)	0.911	5.6 (b)
0.002143	0.36 (a)	0.1214	2.3 (b)	1.062	5.9 (b)
0.00308	0.44 (a)	0.1518	2.5 (b)	1.214	6.3 (b)
0.00311	0.51 (a)	0.1821	2.7 (b)	1.336	6.5 (b)
0.00374	0.54 (a)	0.2125	2.9 (b)	1.821	7.8 (b)
0.00619	0.65 (a)	0.2428	3.1 (b)	2.003	8.5 (b)
0.00740	0.71 (a)	0.2732	3.3 (b)	2.270	11.6 (c)
0.01518	0.98 (b)	0.304	3.4 (b)	2.846	14.1 (c)
0.01821	1.05 (b)	0.364	3.7 (b)	3.94	18.4 (c)
0.02125	1.12 (b)	0.425	4.0 (b)		
0.02428	1.19 (b)	0.455	4.1 (b)		

Experimental:
(a) Pack, et al., Phys. Rev. 121, 798 (1961), data taken at 300 °K.
(b) Robertson, J. Phys. B 5, 648 (1972), data taken at 293 °K.
(c) Nielsen, Phys. Rev. 50, 950 (1936), data taken at 293 °K.

Table 1.4(b)

Values of W for neon at 77 °K

E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)
0.001594	0.42	0.01594	1.06	0.1195	2.32
0.002390	0.51	0.01992	1.15	0.1594	2.62
0.00319	0.57	0.02390	1.24	0.1992	2.88
0.00398	0.62	0.0319	1.38	0.2104	2.95
0.00478	0.67	0.0398	1.50	0.2390	3.1
0.00558	0.71	0.0478	1.61	0.319	3.6
0.00637	0.75	0.0558	1.71	0.398	3.9
0.00717	0.78	0.0637	1.80	0.478	4.2
0.00797	0.82	0.0717	1.88	0.526	4.4
0.01195	0.95	0.0797	1.96	0.558	4.6
				0.637	4.8

Experimental:
All data taken from Robertson, J. Phys. B 5, 648 (1972).

Table 1.5

Values of W for argon in the range $0.3 \times 10^{-17} < E/N < 40 \times 10^{-17} Vcm^2$

E/N ($10^{-17} Vcm^2$)	W (10^6 cm/sec)		E/N ($10^{-17} Vcm^2$)	W (10^6 cm/sec)		E/N ($10^{-17} Vcm^2$)	W (10^6 cm/sec)	
0.304	0.246	(a)	2.526	0.39	(b)	7.56	0.81	(d)
0.307	0.271	(b)	2.572	0.46	(d)	7.61	0.72	(c)
0.362	0.276	(b)	2.615	0.44	(a)	7.82	0.85	(a)
0.379	0.242	(c)	2.825	0.40	(b)	8.32	0.79	(c)
0.412	0.280	(d)	2.965	0.45	(a)	8.41	0.93	(a)
0.428	0.239	(e)	3.03	0.37	(c)	8.48	0.92	(d)
0.441	0.281	(b)	3.08	0.40	(b)	8.90	0.99	(a)
0.444	0.269	(a)	3.18	0.47	(d)	9.15	0.87	(c)
0.471	0.259	(d)	3.33	0.41	(b)	9.39	1.06	(a)
0.488	0.257	(c)	3.41	0.47	(a)	9.69	0.93	(c)
0.530	0.285	(d)	3.63	0.39	(c)	9.78	1.12	(a)
0.543	0.289	(b)		0.40	(b)	10.27	0.98	(c)
0.627	0.270	(c)	3.78	0.49	(a)	10.30	1.19	(a)
0.685	0.296	(b)	3.79	0.41	(b)	10.58	1.15	(d)
0.700	0.30	(a)	3.99	0.50	(a)	11.07	1.29	(a)
0.719	0.269	(e)	4.06	0.43	(b)	11.08	1.05	(c)
0.779	0.282	(c)	4.11	0.41	(c)	11.18	1.05	(c)
0.811	0.30	(b)	4.30	0.52	(a)	11.83	1.12	(c)
0.883	0.30	(d)	4.40	0.50	(d)	11.91	1.40	(a)
0.903	0.292	(c)	4.44	0.46	(b)	11.97	1.12	(c)
0.918	0.292	(e)	4.57	0.44	(c)	12.49	1.31	(d)
0.957	0.32	(a)	4.60	0.53	(a)	12.84	1.52	(a)
0.962	0.32	(d)	4.76	0.54	(a)	13.00	1.19	(c)
0.976	0.31	(b)	4.82	0.49	(b)	13.63	1.63	(a)
1.060	0.32	(d)	5.01	0.46	(c)	14.09	1.32	(c)
1.119	0.31	(c)	5.04	0.57	(a)	14.40	1.73	(a)
1.220	0.33	(b)	5.19	0.52	(b)	15.17	1.83	(a)
1.261	0.35	(a)	5.34	0.49	(c)	15.49	1.43	(c)
1.334	0.32	(c)	5.38	0.55	(d)	16.16	1.97	(a)
1.403	0.31	(e)	5.40	0.57	(d)	17.40	1.55	(c)
1.433	0.35	(d)	5.41	0.49	(c)	19.25	1.73	(c)
1.517	0.37	(a)		0.54	(b)	21.55	1.94	(c)
1.519	0.35	(b)	5.42	0.59	(a)	24.22	2.42	(f)
1.571	0.36	(d)	5.63	0.57	(b)	25.86	2.23	(c)
1.594	0.33	(c)	5.65	0.66	(d)	27.38	2.71	(f)
1.649	0.36	(d)	5.72	0.52	(c)	27.91	2.43	(g)
1.660	0.33	(e)	5.81	0.63	(a)	30.6	2.61	(c)
1.763	0.36	(b)		0.53	(c)	32.4	2.91	(g)
1.844	0.39	(a)	6.14	0.66	(a)	32.9	3.2	(f)
1.904	0.39	(d)	6.46	0.70	(a)	34.9	3.5	(f)
1.976	0.35	(c)	6.47	0.61	(c)	36.4	3.4	(g)
1.991	0.38	(b)	6.52	0.66	(d)	37.3	3.1	(c)
2.241	0.41	(a)	6.93	0.75	(a)	38.9	3.2	(g)
2.274	0.39	(b)	7.11	0.66	(c)			
2.452	0.36	(c)	7.35	0.79	(a)			

Experimental:

(a) Herreng, Compt. Rend. 217, 75 (1943).
(b) Levine, J. Appl. Phys. 35, 2618 (1964).
(c) Errett, Ph.D. Thesis, Purdue University, 1951.
(d) Nielsen, Phys. Rev. 50, 950 (1936).
(e) Pack, *et al.*, Phys. Rev. 121, 798 (1961).
(f) Caren, Phys. Rev. 131, 1904 (1963).
(g) Jager, *et al.*, Z. Physik 169, 517 (1962).

Table 1.6(a)

Values of W for argon for E/N < 0.3 × 10^{-17} Vcm^2 at 300 K

E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)		E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)		E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)	
0.0001	0.0122	(1)	0.00330	0.65	(a)	0.03436	1.29	(a)
0.000625	0.080	(a)	0.00499	0.84	(a)	0.0525	1.42	(a)
0.000631	0.087	(a)	0.01005	1.01	(a)	0.1045	1.78	(a)
0.001107	0.157	(a)	0.02042	1.15	(a)	0.1758	1.91	(a)
0.001622	0.205	(a)	0.02523	1.15	(a)	0.2123	2.27	(a)
0.002506	0.46	(a)				0.2148	2.00	(a)

Experimental:
(a) Pack, et al., Phys. Rev. 121, 798 (1961).
Theoretical:
(1) Frost, et al., Phys. Rev. 136, A1538 (1964).

Table 1.6(b)

Values of W for argon for E/N < 0.3 × 10^{-17} Vcm^2 at 77 K

E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)		E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)		E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)	
0.0001	0.0056	(1)	0.001622	{0.095	(a)	0.00499	0.65	(a)
0.000625	0.036	(a)		0.099}	(a)	0.00664	0.94	(a)
0.000781	{0.044	(a)	0.002478	0.169	(a)	0.01688	1.12	(a)
	0.050}	(a)	0.002613	0.161	(a)	0.0698	1.53	(a)
0.000955	0.052	(a)	0.00330	0.243	(a)	0.2655	2.15	(a)

Experimental:
(a) Pack, et al., Phys. Rev. 121, 798 (1961).
Theoretical:
(1) Frost, et al., Phys. Rev. 136, A1538 (1964).

Table 1.7

Values of W for argon for E/N > 50 × 10^{-17}Vcm^2

E/N (10^{-17}Vcm^2)	W (10^7cm/sec)		E/N (10^{-17}Vcm^2)	W (10^7cm/sec)		E/N (10^{-17}Vcm^2)	W (10^7cm/sec)	
52.8	0.40	(b)	93.0	0.62	(b)	170.9	0.98	(b)
53.6	0.43	(a)	97.6	0.63	(b)	172.8	1.01	(b)
54.9	{0.41	(b)	99.5	0.63	(b)	174.3	1.04	(b)
	0.44	(b)	99.7	0.74	(c)	174.5	0.98	(b)
56.7	0.45	(b)	104.3	0.68	(b)	177.7	1.55	(1)
57.3	0.50	(a)	115.3	0.83	(c)	177.8	0.99	(b)
58.6	0.44	(b)	116.5	0.72	(b)	179.1	1.10	(b)
58.8	0.60	(1)	117.3	0.76	(b)	180.6	0.99	(b)
62.0	0.45	(b)	118.9	1.12	(1)	187.2	1.22	(a)
62.6	0.48	(b)	119.5	0.87	(c)	187.3	1.10	(b)
66.0	0.49	(b)	120.2	0.73	(b)	194.6	1.17	(b)
71.0	0.51	(b)	121.3	0.77	(b)	216.1	1.84	(1)
73.1	0.54	(b)	125.5	0.77	(b)	250.0	2.10	(1)
73.6	0.56	(c)	133.4	0.84	(b)	277.4	2.31	(1)
77.9	0.54	(b)	144.5	0.91	(b)	318	2.60	(1)
86.2	0.85	(1)	148.3	0.85	(b)	359	2.88	(1)
87.2	0.66	(c)	149.4	1.34	(1)	398	3.2	(1)
88.0	{0.60	(b)	150.0	1.00	(a)	438	3.4	(1)
	0.69	(a)	150.4	0.87	(b)	480	3.7	(1)
90.1	0.60	(b)	157.5	0.96	(b)	523	4.0	(1)
90.8	0.60	(a)	163.8	0.97	(b)	550	4.2	(1)
						585	4.5	(1)

Experimental:
(a) Jager, et al., Z. Physik 169, 517 (1962).
(b) Brambring, Z. Physik 179, 539 (1964).
(c) Wagner, Z. Physik 178, 64 (1964).
Theoretical:
(1) Golant, Sov. Phys.-Tech. Phys. 4, 680 (1959).

Table 1.8

Values of W_M for argon

E/N (10^{-17}Vcm^2)	W_M (10^7cm/sec)		E/N (10^{-17}Vcm^2)	W_M (10^7cm/sec)		E/N (10^{-17}Vcm^2)	W_M (10^7cm/sec)	
0.0001	0.000057	(1)	0.01	0.0150	(1)	1.252	0.036	(a)
0.0007	0.00040	(1)	0.02	0.0178	(1)	2.518	0.059	(a)
0.0015	0.00087	(1)	0.0329	0.0196	(1)	3.0	0.050	(1)
0.002	0.00133	(1)	0.104	0.0240	(1)	6.32	0.152	(a)
0.0025	0.00228	(1)	0.329	0.030	(1)	8.43	0.226	(a)
0.003	0.0041	(1)	0.334	0.031	(a)	12.67	0.34	(a)
0.0035	0.0063	(1)	0.501	0.032	(a)	17.58	0.46	(a)
0.0045	0.0097	(1)	0.626	0.033	(a)	26.11	0.60	(a)
0.0065	0.0128	(1)	1.04	0.039	(1)	36.1	0.73	(a)
						59.0	0.95	(a)

Experimental:
(a) Townsend, et al., Phil. Mag. 44, 1033 (1922).
Theoretical:
(1) Engelhardt, et al., Phys. Rev. 133, A375 (1964).

Table 1.9(a)

Values of W for krypton at ambient temperatures and above

E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)		E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)		E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)	
0.000791	0.0108	(a)	0.00774	0.106	(a)	0.0306	1.04	(a)
0.000924	0.0128	(a)	0.00918	0.133	(a)	0.0758	1.27	(a)
0.001525	0.0226	(b)	0.01254	0.210	(a)	0.1496	1.34	(a)
0.002144	0.031	(b)	0.01550	0.33	(a)	0.304	1.57	(a)
0.00306	0.042	(b)	0.01712	0.42	(a)	0.609	1.78	(a)
0.00308	0.036	(a)	0 01838	0.51	(a)	0.892	2.00	(a)
0.00458	0.058	(a)	0.02118	0.62	(a)	1.53	2.30	(a)
0.00461	0.066	(b)	0.02440	0.86	(a)	1.786	2.51	(a)
0.00617	0.085	(a)	0.02772	1.04	(a)	2.440	2.51	(a)
0.00622	0.095	(b)				3.06	3.2	(a)

Experimental:
(a) Pack, et al., Phys. Rev. 127, 2084 (1962), data taken at 300 K.
(b) Ibid., data taken at 368 K.

Table 1.9(b)

Values of W for krypton at 195 K

E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)
0.001210	0.0158	0.00465	0.052	0.01891	0.40
0.001561	0.0174	0.00617	0.069	0.02475	0.80
0.001851	0.0238	0.00918	0.109	0.0442	1.19
0.00308	0.038	0.01236	0.162	0.0924	1.27

Experimental:
Pack, et al., Phys. Rev. 127, 2084 (1962).

Table 1.10(a)

Values of W for xenon at 300 K

E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)
0.001542	0.0058 (a)	0.0499	0.50 (a)	1.837	1.57 (a)
0.00305	0.0126 (a)	0.0552	0.60 (a)	2.178	1.64 (a)
0.00454	0.0188 (a)	0.0618	0.70 (a)	2.735	1.76 (a)
0.00611	0.0250 (a)	0.0692	0.73 (a)	3.15	1.86 (a)
0.00767	0.0292 (a)	0.0918	0.82 (a)	129.5	85 (b)
0.00923	0.037 (a)	0.1074	0.89 (a)	132.8	81 (b)
0.01225	0.047 (a)	0.1239	0.90 (a)	141.4	98 (b)
0.01393	0.054 (a)	0.1556	0.97 (a)	142.5	88 (b)
0.01560	0.062 (a)	0.1871	0.97 (a)	147.1	92 (b)
0.01849	0.059 (a)	0.2483	1.01 (a)	153.9	101 (b)
0.02163	0.087 (a)	0.307	1.10 (a)	159.5	98 (b)
0.02355	0.101 (a)	0.386	1.13 (a)	162.7	108 (b)
0.02754	0.128 (a)	0.463	1.10 (a)	169.3	114 (b)
0.0308	0.163 (a)	0.652	1.25 (a)	206.9	134 (b)
0.0366	0.256 (a)	0.916	1.31 (a)	224.1	141 (b)
0.0428	0.41 (a)	1.216	1.46 (a)	225.9	147 (b)
0.0466	0.45 (a)	1.528	1.53 (a)	261.9	155 (b)
				291.3	173 (b)

Experimental:
(a) Pack, et al., Phys. Rev. 127, 2084 (1962).
(b) Wagner, Z. Physik 178, 64 (1964).

Table 1.10(b)

Values of W for xenon at 195 K

E/N (10^{-17} Vcm^2)	W (10^4 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^4 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^4 cm/sec)
0.00301	0.095	0.01849	0.75	0.0376	1.84
0.00603	0.199	0.02422	0.80	0.0459	2.98
0.01208	0.428	0.0304	1.21	0.0618	5.9
				0.07537	7.3

Experimental:
Pack, et al., Phys. Rev. 127, 2084 (1962).

Table 1.11(a)

Values of W for hydrogen for E/N < 2.8 × 10^{-17} Vcm^2 at ambient temperatures

E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)		E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)		E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)	
0.001174	0.0217	(a)	0.0303	0.46	(b)	0.303	3.2	(b)
0.001254	0.0203	(a)	0.0364	0.55	(b)	0.364	3.6	(b)
0.001528	0.0245	(a)	0.0455	0.68	(b)	0.455	4.1	(b)
0.002330	0.037	(a)	0.0546	0.80	(b)	0.546	4.6	(b)
0.002488	0.039	(a)	0.0606	0.88	(b)	0.606	4.9	(b)
0.00303	0.052	(a)	0.0758	1.07	(b)	0.758	5.5	(b)
0.00307	0.047	(a)	0.0909	1.26	(b)	0.909	6.0	(b)
0.01212	0.188	(b)	0.1212	1.59	(b)	1.212	6.8	(b)
0.01516	0.235	(b)	0.1516	1.89	(b)	1.516	7.5	(b)
0.01819	0.283	(b)	0.1819	2.18	(b)	1.819	8.0	(b)
0.02122	0.33	(b)	0.2122	2.45	(b)	2.122	8.6	(b)
0.02425	0.37	(b)	0.2425	2.70	(b)	2.425	9.1	(b)
0.02728	0.42	(b)	0.2728	2.94	(b)	2.728	9.6	(b)

Experimental:
(a) Pack, et al., Phys. Rev. 121, 798 (1961), data taken at 300 K.
(b) Lowke, Austr. J. Phys. 16, 115 (1963), data taken at 293 K.

Table 1.11(b)

Values of W for hydrogen for E/N < 0.3 × 10^{-17} Vcm^2 at 77 K

E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)		E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)		E/N (10^{-17} Vcm^2)	W (10^5 cm/sec)	
0.00303	0.108	(b)	0.02425	0.66	(b)	0.0795	1.47	(a)
0.00364	0.129	(b)	0.02728	0.72	(b)	0.0909	1.62	(b)
0.00455	0.158	(b)	0.0303	0.77	(b)	0.0954	1.67	(a)
0.00546	0.188	(b)	0.0318	0.79	(a)	0.1193	1.95	(a)
0.00606	0.207	(b)	0.0364	0.87	(b)	0.1212	1.97	(b)
0.00758	0.254	(b)	0.0398	0.92	(a)	0.1431	2.21	(a)
0.00795	0.273	(a)	0.0455	1.01	(b)	0.1516	2.32	(b)
0.00909	0.297	(b)	0.0477	1.04	(a)	0.1590	2.38	(a)
0.01212	0.383	(b)	0.0546	1.14	(b)	0.1819	2.62	(b)
0.01516	0.46	(b)	0.0557	1.15	(a)	0.1988	2.77	(a)
0.01590	0.48	(a)	0.0606	1.23	(b)	0.2122	2.90	(b)
0.01819	0.53	(b)	0.0636	1.26	(a)	0.2386	3.12	(a)
0.02122	0.59	(b)	0.0716	1.37	(a)	0.2425	3.2	(b)
0.02386	0.64	(a)	0.0758	1.43	(b)	0.2728	3.4	(b)
						0.2783	3.4	(a)

Experimental:
(a) Robertson, Austr. J. Phys. 24, 445 (1971).
(b) Lowke, Austr. J. Phys. 16, 115 (1963).

Table 1.12

Values of W for hydrogen for $2.8 \times 10^{-17} < E/N < 110 \times 10^{-17} Vcm^2$ at ambient temperatures

E/N ($10^{-17} Vcm^2$)	W (10^7 cm/sec)		E/N ($10^{-17} Vcm^2$)	W (10^7 cm/sec)		E/N ($10^{-17} Vcm^2$)	W (10^7 cm/sec)	
3.03	0.101	(a)	20.	0.281	(b)	58.1	0.65	(e)
3.64	0.110	(a)	21.22	0.295	(a)	60.6	0.70	(c)
4.	0.115	(b)	22.	0.297	(b)	62.3	0.72	(e)
4.55	0.123	(a)	24.	0.31	(b)	64.2	0.74	(d)
5.46	0.135	(a)	24.25	0.32	(a)	68.9	0.77	(e)
6.	0.141	(b)	26.	0.33	(b)	69.6	0.80	(d)
6.06	0.143	(a)	27.28	0.34	(a)	73.8	0.90	(d)
7.58	0.161	(a)	30.3	0.37	(a)	75.8	0.92	(c)
8.	0.165	(b)	36.4	{0.42	(a)	78.1	0.94	(e)
9.09	0.179	(a)		0.42	(c)	80.8	0.98	(d)
10.	0.187	(b)	45.5	{0.51	(a)	84.0	1.01	(e)
12.	0.207	(b)		0.51	(c)	88.3	{1.10	(e)
12.12	0.210	(a)	54.6	{0.63	(a)		1.14	(d)
14.	0.227	(b)		0.62	(c)	90.9	1.15	(c)
15.16	0.240	(a)	54.7	0.57	(d)	92.1	1.17	(d)
16.	0.246	(b)	56.7	0.60	(e)	97.0	1.22	(e)
18.	0.264	(b)	57.5	{0.66	(d)	106.1	1.38	(c)
18.19	0.267	(a)		0.63	(e)			

Experimental:
(a) Lowke, Austr. J. Phys. 16, 115 (1963).
(b) Robertson, Austr. J. Phys. 24, 445 (1971).
(c) Blevin, et al., Austr. J. Phys. 20, 735 (1967).
(d) Jager, et al., Z. Physik 169, 517 (1962).
(e) Frommhold, Z. Physik 160, 554 (1960).

Table 1.13

Values of W for hydrogen for $E/N > 120 \times 10^{-17} Vcm^2$ at ambient temperatures

E/N ($10^{-17} Vcm^2$)	W (10^8 cm/sec)		E/N ($10^{-17} Vcm^2$)	W (10^8 cm/sec)		E/N ($10^{-17} Vcm^2$)	W (10^8 cm/sec)	
121.2	0.168	(a)	270.0	0.43	(b)	952	1.12	(b)
136.4	0.189	(a)	338	0.53	(b)	992	1.20	(b)
136.6	0.207	(b)	387	0.59	(b)	1347	1.32	(b)
151.6	0.216	(a)	444	0.67	(b)	1587	1.51	(b)
183.1	0.31	(b)	646	0.86	(b)	2231	1.98	(b)
227.7	0.41	(b)	760	0.95	(b)	2505	1.83	(b)
						5260	2.62	(b)

Experimental:
(a) Blevin, et al., Austr. J. Phys. 20, 735 (1967).
(b) Schlumbohm, Z. Physik 182, 317 (1965).

Table 1.14(a)

Values of W showing the dependence of W on N at various values of E/N in hydrogen at 77 K

$N(cm^{-3})$	1.257×10^{19}	2.515×10^{19}	3.772×10^{19}	5.030×10^{19}	6.287×10^{19}	7.544×10^{19}	8.802×10^{19}
$E/N(10^{-17}Vcm^2)$				$W(10^5 cm/sec)$			
0.01590		0.478	0.477	0.476	0.476	0.475	0.474
0.02386	0.648	0.645	0.644	0.644	0.644	0.644	0.644
0.0318		0.789	0.788	0.788	0.789	0.789	0.789
0.0398	0.921	0.918	0.917	0.917	0.917	0.918	0.918
0.0477	1.04	1.04	1.04	1.04	1.04	1.04	1.04
0.0557	1.16	1.15	1.15	1.15	1.15	1.15	1.15
0.0636	1.27	1.26	1.26	1.26	1.26	1.26	1.26
0.0716	1.37	1.37	1.37	1.36	1.36	1.36	1.36
0.0795	1.48	1.47	1.47	1.47	1.47	1.46	1.46
0.0954	1.68	1.67	1.66	1.66	1.66	1.66	1.66
0.1193	1.95	1.95	1.94	1.94	1.94	1.94	1.93
0.1431	2.21	2.21	2.20	2.20	2.20	2.19	2.19
0.1590	2.38	2.37	2.37	2.36	2.36	2.36	
0.1988	2.76	2.76	2.75	2.75	2.74		

Experimental:
All data taken from Robertson, Austr. J. Phys. 24, 445 (1971).

Table 1.14(b)

Values of W showing the dependence of W on N at various values of E/N in hydrogen at ambient temperatures

$N(cm^{-3})$	1.110×10^{21}	8.380×10^{20}	6.000×10^{20}	1.300×10^{20}	2.744×10^{19}	
$E/N(10^{-17}Vcm^2)$			$W(10^6 cm/sec)$			
0.006			0.0084			(a)
0.008	0.0111	0.0118	0.0124			(a)
0.011	0.0147	0.0155	0.0164			(a)
0.014	0.0182	0.0194	0.0207			(a)
0.017	0.0220	0.0234	0.0246			(a)
0.020	0.0255	0.0275	0.0287			(a)
0.023	0.0290	0.0310	--			(a)
0.025	0.0326	0.0351	0.0368			(a)
0.028	0.036	0.039	0.0405			(a)
0.034	0.043	0.046	--			(a)
0.042	0.054	0.057	--			(a)
0.051	0.064	0.068	--			(a)
0.057	0.072	0.075	0.078			(a)
0.071	0.088	0.092	0.095			(a)
0.085	0.103	0.107	0.111			(a)
0.0909	0.101		0.110	0.126	0.129	(b)
0.1212	0.133		0.145	0.159	0.164	(b)
0.1819	0.185		0.198	0.215	--	(b)
0.2425	0.235		0.246	0.266	0.275	(b)
0.364	0.305		0.317	0.334	--	(b)
0.485	0.373		0.399	0.421	0.430	(b)
0.728	0.488		0.510	0.518	0.533	(b)
0.970	0.563		0.584	0.598	0.612	(b)
2.425	0.842		0.867	0.886	0.890	(b)
4.85	1.17		1.20	1.22	1.24	(b)
9.09	1.65		1.71	1.715	1.73	(b)
12.12	1.98		2.05	2.035	2.04	(b)
18.19			2.54	2.55	2.60	(b)
24.25				3.08	3.06	(b)
36.4				4.02	4.07	(b)

Experimental:
(a) Grünberg, Z. Naturforsch. 23A, 1994 (1968).
(b) Grünberg, Z. Physik 204, 12 (1967).

Table 1.15

Values of W_M for hydrogen

E/N (10^{-17}Vcm^2)	W_M (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W_M (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W_M (10^5cm/sec)
0.0610	1.07 (a)	1.820	9.33 (a)	24.28	33.7 (a)
0.0760	1.29 (a)	2.130	9.93 (a)	27.30	36.3 (a)
0.0920	1.49 (a)	2.430	10.5 (a)	40.2	49 (b)
0.1210	1.87 (a)	2.569	11.2 (b)	41.4	49 (b)
0.1520	2.22 (a)	2.730	11.0 (a)	81.7	103 (b)
0.1820	2.53 (a)	3.03	11.5 (a)	84.8	109 (b)
0.2120	2.83 (a)	3.64	12.5 (a)	87.8	114 (b)
0.2430	3.11 (a)	4.55	13.8 (a)	90.8	118 (b)
0.2730	3.39 (a)	5.10	15.2 (b)	94.5	125 (b)
0.303	3.63 (a)	5.46	15.1 (a)	99.1	132 (b)
0.455	4.74 (a)	6.07	16.0 (a)	103.9	140 (b)
0.607	5.59 (a)	9.11	19.7 (a)	106.9	145 (b)
0.632	6.0 (b)	10.10	21.6 (b)	110.7	150 (b)
0.659	6.3 (b)	12.14	23.0 (a)	113.6	156 (b)
0.911	6.90 (a)	15.18	25.9 (a)	117.1	162 (b)
1.210	7.88 (a)	18.21	28.6 (a)	120.9	168 (b)
1.267	8.5 (b)	20.24	32 (b)	125.0	175 (b)
1.520	8.63 (a)	21.25	31.2 (a)	129.0	182 (b)
				133.6	189 (b)

Experimental:
(a) Creaser, Austr. J. Phys. 20, 547 (1967).
(b) Townsend, et al., Phil. Mag. 42, 874 (1921).

Table 1.16

Values of W for nitrogen for E/N < 56 × 10^{-17}Vcm^2

E/N (10^{-17}Vcm^2)	W (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W (10^5cm/sec)
0.01212	0.46	0.2122	2.90	3.03	7.7
0.01516	0.56	0.2425	2.96	3.64	8.7
0.01819	0.67	0.2728	3.03	4.55	10.2
0.02122	0.77	0.303	3.09	5.46	11.7
0.02425	0.88	0.364	3.22	6.06	12.7
0.02728	0.97	0.455	3.43	7.58	14.9
0.0303	1.07	0.546	3.63	9.09	17.1
0.0364	1.25	0.606	3.76	12.12	21.1
0.0455	1.49	0.758	4.02	15.16	25.0
0.0546	1.71	0.909	4.28	18.19	28.8
0.0606	1.82	1.212	4.76	21.22	32.3
0.0758	2.08	1.516	5.2	24.25	35.7
0.0909	2.28	1.819	5.7	27.28	39.0
0.1212	2.55	2.122	6.2	30.31	42.0
0.1516	2.71	2.425	6.7	36.4	48.2
0.1819	2.81	2.728	7.2	45.5	56.8
				54.6	65.1

Experimental:
All results taken from Lowke, Austr. J. Phys. 16, 115 (1963).

Table 1.17

Values of W for nitrogen for $60 \times 10^{-17} < E/N < 500 \times 10^{-17} Vcm^2$

E/N ($10^{-17} Vcm^2$)	W (10^7 cm/sec)	Ref.	E/N ($10^{-17} Vcm^2$)	W (10^7 cm/sec)	Ref.	E/N ($10^{-17} Vcm^2$)	W (10^7 cm/sec)	Ref.
60.6	0.69	(a)	118.8	1.22	(e)	151.6	1.62	(b)
	0.70	(b)	119.2	1.23	(e)	151.7	1.51	(d)
61.6	0.72	(c)	120.5	1.25	(c)	153.5	1.51	(f)
68.6	0.79	(c)	120.6	1.17	(f)	155.6	1.46	(f)
73.1	0.83	(c)		1.23	(e)	161.6	1.62	(f)
75.8	0.82	(a)	121.0	1.25	(c)	164.2	1.58	(d)
	0.84	(b)		1.23	(e)	166.7	1.77	(b)
79.1	0.87	(c)	121.2	1.23	(a)	177.5	1.74	(f)
86.7	0.95	(c)		1.29	(b)	181.9	1.95	(b)
86.9	0.94	(c)	122.2	1.25	(e)	208.0	1.96	(f)
90.9	0.95	(a)	122.8	1.25	(e)	212.2	2.24	(b)
	0.97	(b)	123.9	1.26	(e)	227.3	2.43	(b)
91.0	0.99	(c)	124.9	1.27	(e)	242.5	2.53	(b)
95.1	1.02	(c)	125.4	1.28	(e)	243.0	2.23	(f)
104.0	1.10	(c)	126.9	1.29	(e)	254.8	2.40	(d)
104.4	1.09	(e)	127.4	1.29	(e)	275.5	2.63	(d)
106.0	1.12	(e)	128.8	1.31	(e)	278.6	2.62	(g)
106.1	1.12	(a)	128.9	1.25	(f)	319	3.4	(h)
	1.11	(b)	129.3	1.31	(e)	326	3.1	(g)
106.5	1.09	(f)	130.9	1.32	(e)	330	3.3	(d)
106.9	1.11	(c)	132.3	1.31	(f)	333	3.1	(g)
107.8	1.13	(e)	132.9	1.34	(e)	337	3.1	(d)
109.3	1.15	(e)	135.0	1.36	(e)	347	3.4	(g)
109.9	1.11	(f)	136.4	1.44	(b)	352	3.4	(d)
110.8	1.15	(e)	136.9	1.37	(e)	371	3.5	(g)
110.9	1.13	(f)	138.9	1.40	(e)	375	3.5	(d)
112.6	1.17	(e)	141.0	1.41	(e)	378	3.4	(g)
113.3	1.17	(c)	143.0	1.43	(e)	387	3.5	(d)
113.8	1.13	(f)	144.6	1.46	(f)	400	3.9	(g)
114.1	1.18	(e)	145.0	1.45	(e)	403	3.9	(d)
115.8	1.19	(e)	147.1	1.46	(e)	446	4.5	(g)
117.4	1.21	(e)	149.1	1.49	(e)	450	4.5	(d)
117.5	1.15	(f)	149.6	1.41	(f)	467	4.0	(h)

Experimental:

(a) Fischer-Treuenfeld, Z. Physik 185, 336 (1965).
(b) Blevin, et al., Austr. J. Phys. 20, 741 (1967).
(c) Prasad, et al., Brit. J. Appl. Phys. 18, 371 (1967).
(d) Wagner, Z. Physik 178, 64 (1964).
(e) Tholl, Z. Physik 178, 183 (1964).
(f) Frommhold, Z. Physik 160, 554 (1960).
(g) Wagner, et al., Z. Physik 170, 540 (1962).
(h) Schlumbohm, Z. Physik 182, 317 (1965).

Table 1.18

Values of W for nitrogen for E/N > 500 × 10^{-17}Vcm^2

E/N (10^{-17}Vcm^2)	W (10^8cm/sec)	E/N (10^{-17}Vcm^2)	W (10^8cm/sec)	E/N (10^{-17}Vcm^2)	W (10^8cm/sec)
597	0.42	1253	0.66	2647	1.01
706	0.50	1540	0.85	3560	1.05
955	0.58	1775	0.85	5240	1.34
				8240	1.64

Experimental:
All data taken from Schlumbohm, Z. Physik 182, 317 (1965).

Table 1.19(a)

Values of W for nitrogen at 473 K

E/N (10^{-17}Vcm^2)	W (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W (10^5cm/sec)
0.0617	1.17	0.617	3.6	3.70	8.1
0.1234	1.90	1.234	4.6	4.32	8.9
0.1851	2.48	1.851	5.4	4.96	9.9
0.2468	2.75	2.468	6.3	5.55	10.7
0.309	2.99	3.09	7.2		

Experimental:
All data taken from Hendrick, et al., ORNL-TM-1444, Oak Ridge National Laboratory, Oak Ridge, Tennessee (1968).

Table 1.19(b)

Values of W for nitrogen at 77 K

E/N (10^{-17}Vcm^2)	W (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W (10^5cm/sec)
0.000306	0.041	0.00303	0.40	0.1188	3.8
0.000455	0.053	0.00600	0.76	0.1449	3.8
0.000615	0.077	0.0147	1.77	0.1762	3.8
0.000760	0.106	0.02944	2.78	0.2388	3.6
0.001219	0.147	0.0600	3.7	0.2944	3.6
0.001507	0.200	0.0889	3.9	0.443	3.7

Experimental:
All data taken from Pack, et al., Phys. Rev. 121, 798 (1961).

Table 1.19(c)

Values of W for nitrogen at 195 K

E/N (10^{-17}Vcm^2)	W (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W (10^5cm/sec)	E/N (10^{-17}Vcm^2)	W (10^5cm/sec)
0.000760	0.045	0.00607	0.34	0.0592	2.40
0.001524	0.087	0.0149	0.82	0.0889	2.82
0.00306	0.180	0.02944	1.55	0.1205	2.93
				0.1786	3.1

Experimental:
All data taken from Pack, et al., Phys. Rev. 121, 798 (1961).

Table 1.20

Values of W showing the dependence of W on N at various values of E/N in nitrogen

$N(cm^{-3})$	1.039×10^{21}	1.84×10^{21}	5.233×10^{20}	1.036×10^{20}	2.690×10^{19}	7.82×10^{19}
E/N ($10^{-17} Vcm^2$)	W (10^6 cm/sec)					
0.1212	0.224 (a)		0.242 (a)	0.256 (a)	0.260 (a)	
0.1819	0.264 (a)		0.275 (a)	0.284 (a)	0.284 (a)	
0.2425	0.285 (a)		0.292 (a)	0.298 (a)	0.298 (a)	
0.303	0.307 (a)		0.306 (a)	0.312 (a)	0.312 (a)	
0.455	0.327 (a)		0.336 (a)	0.343 (a)	0.345 (a)	
0.606	0.353 (a)		0.363 (a)	0.368 (a)	0.371 (a)	
0.909	0.404 (a)		0.415 (a)	0.418 (a)	0.422 (a)	
1.212						0.558 (b)
1.263						0.523 (b)
1.516	0.484 (a)		0.493 (a)	0.505 (a)	0.500 (a)	
1.942						0.645 (b)
2.132		0.603 (b)				
2.421		0.623 (b)				
2.425	0.62 (a)		0.637 (a)	0.649 (a)	0.649 (a)	
2.502						0.750 (b)
2.553						0.769 (b)
2.721		0.745 (b)				
3.01		0.781 (b)				
3.24						0.855 (b)
3.33		0.800 (b)				
3.56						0.886 (b)
3.64		0.892 (b)				
3.92		0.909 (b)				0.949 (b)
4.38						1.030 (b)
6.06	1.15 (a)		1.205 (a)	1.225 (a)	1.225 (a)	
9.09	1.60 (a)		1.63 (a)	1.62 (a)	1.64 (a)	
24.25			3.40 (a)	3.33 (a)	3.36 (a)	
36.4				4.68 (a)	4.55 (a)	

Experimental:
(a) Grunberg, Z. Physik 204, 12 (1967).
(b) Allen, *et al.*, J. Phys. B 3, 1113 (1972).

Table 1.21

Values of W_M for nitrogen

E/N (10^{-17}Vcm^2)	W_M (10^7cm/sec)	E/N (10^{-17}Vcm^2)	W_M (10^7cm/sec)	E/N (10^{-17}Vcm^2)	W_M (10^7cm/sec)
0.1212	0.0394 (a)	1.212	0.059 (a)	6.06	0.133 (a)
0.1516	0.0415 (a)	1.267	0.059 (b)	7.58	0.156 (a)
0.1819	0.0427 (a)	1.516	0.062 (a)	9.09	0.179 (a)
0.2122	0.0435 (a)	1.819	0.066 (a)	10.04	0.195 (b)
0.2425	0.0438 (a)	2.122	0.071 [illegible]	12.12	0.225 (a)
0.2728	0.0445 (a)	2.425	0.074 (a)	15.16	0.270 (a)
0.303	0.045 (a)	2.527	0.077 (b)	18.19	0.316 (a)
0.364	0.046 (a)	2.728	0.079 (a)	20.12	0.34 (b)
0.455	0.047 (a)	3.03	0.084 (a)	21.22	0.36 (a)
0.546	0.049 (a)	3.64	0.094 (a)	24.25	0.401 (a)
0.606	0.050 (a)	4.55	0.108 (a)	40.2	0.62 (b)
0.758	0.053 (a)	5.01	0.111 (b)	80.5	1.08 (b)
0.909	0.055 (a)	5.46	0.123 (a)	161.8	1.81 (b)

Experimental:
(a) Jory, Austr. J. Phys. 18, 237 (1965).
(b) Townsend, et al., Phil. Mag. 42, 874 (1921).

Table 1.22

Values of W for oxygen for E/N < 57 × 10^{-17} Vcm^2

E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)	
0.00503	0.050	(a)
0.00810	0.080	(a)
0.01118	0.111	(a)
0.02043	0.216	(a)
0.02968	0.26	(a)
0.0420	0.33	(a)
0.0543	0.39	(a)
0.0697	0.41	(a)
0.0851	0.41	(a)
0.1128	0.47	(a)
0.1186	0.38	(b)
0.1313	0.45	(a)
0.1466	0.47	(b)
0.1467	0.48	(a)
0.1621	0.49	(a)
0.1775	0.51	(a)
0.1786	0.45	(b)
0.2237	0.52	(a)
0.2825	0.55	(c)
0.2853	0.58	(a)
0.301	0.64	(b)
0.347	0.60	(a)
0.493	0.77	(a)
0.565	0.74	(c)
0.597	0.77	(b)
0.616	0.88	(a)
	0.87	(a)
0.770	1.00	(a)
	0.99	(a)
0.906	1.14	(b)
0.924	1.12	(a)
1.078	1.23	(a)
1.186	1.33	(b)
1.232	1.34	(a)
1.264	1.50	(d)
1.386	1.43	(a)
1.412	1.51	(c)
1.44	1.69	(e)
1.486	1.46	(b)
1.540	1.52	(a)
1.686	1.93	(d)
1.694	1.61	(a)
1.695	1.40	(f)
1.756	1.79	(d)
1.848	1.69	(a)

E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)	
2.002	1.77	(a)
2.156	1.85	(a)
2.310	1.91	(a)
2.318	2.09	(d)
2.464	1.99	(a)
2.618	2.05	(a)
2.772	2.10	(a)
2.825	2.50	(c)
2.880	2.43	(d)
2.926	2.16	(a)
2.965	2.38	(b)
3.00	2.23	(e)
3.080	2.22	(a)
3.14	2.00	(f)
3.37	2.45	(d)
3.38	2.20	(f)
3.73	2.45	(f)
4.14	2.54	(d)
4.27	2.67	(d)
4.49	2.70	(f)
4.50	2.56	(e)
4.55	2.70	(f)
4.64	2.70	(d)
4.72	2.70	(f)
5.27	2.76	(d)
5.34	2.80	(f)
5.65	2.99	(c)
5.77	2.63	(b)
5.91	2.74	(d)
5.97	2.74	(e)
6.16	2.95	(f)
6.24	2.94	(d)
6.50	3.00	(f)
6.81	3.05	(f)
6.94	3.0	(d)
7.06	3.1	(f)
7.24	3.0	(d)
7.58	2.95	(e)
7.77	3.2	(f)
8.37	3.3	(d)
8.42	3.3	(f)
8.48	3.2	(c)
8.50	3.4	(f)
8.93	3.3	(b)
9.12	3.5	(f)
	3.1	(e)

E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)	
9.32	3.5	(f)
9.76	3.6	(d)
9.92	3.7	(f)
10.59	3.3	(e)
10.90	3.9	(f)
11.03	3.8	(d)
11.30	3.5	(c)
11.89	4.0	(f)
12.24	3.5	(e)
12.57	4.0	(d)
13.31	4.4	(f)
13.67	3.8	(e)
14.10	4.6	(f)
14.12	3.9	(c)
14.55	4.4	(d)
14.86	4.4	(b)
15.28	3.9	(e)
15.82	5.0	(f)
15.88	4.0	(g)
16.10	4.8	(d)
	5.7	(f)
16.60	4.4	(e)
16.95	4.3	(c)
17.35	4.9	(d)
17.66	5.8	(f)
18.24	4.5	(e)
18.36	5.5	(f)
18.76	5.3	(d)
18.82	5.3	(d)
19.49	5.8	(f)
19.63	5.1	(e)
19.77	4.8	(c)
21.07	6.2	(f)
22.07	6.0	(d)
22.60	5.5	(c)
22.63	6.6	(f)
24.42	5.7	(e)
25.42	6.1	(c)
25.71	7.3	(f)
28.04	7.5	(d)
28.25	6.8	(c)
28.33	7.9	(f)
29.65	8.8	(b)
30.4	7.9	(d)
30.5	6.1	(g)
31.1	7.5	(c)

Table 1.22 (continued)

Values of W for oxygen for E/N < 57 × 10^{-17}Vcm^2

E/N (10^{-17}Vcm^2)	W (10^6cm/sec)		E/N (10^{-17}Vcm^2)	W (10^6cm/sec)		E/N (10^{-17}Vcm^2)	W (10^6cm/sec)	
33.9	8.2	(c)	42.4	9.8	(c)	48.0	10.8	(c)
36.4	9.2	(d)	44.6	10.7	(d)	50.8	11.3	(c)
36.5	8.8	(d)	44.8	10.9	(d)	52.9	11.6	(d)
36.7	8.7	(c)	45.0	8.8	(g)	53.7	11.7	(c)
39.6	9.3	(c)	45.2	10.3	(c)	56.5	12.0	(c)

Experimental:
(a) Nelson, et al., J. Chem. Phys. 57, 4079 (1972).
(b) Pack, as given in Hake, et al., Phys. Rev. 158, 70 (1967).
(c) Herreng, Cahiers Phys. 38, 6 (1952).
(d) Nielsen, et al., Phys. Rev. 51, 69 (1937).
(e) Fleming, et al., J. Phys. D 5, 291 (1972).
(f) Doehring, Z. Naturforsch. 7A, 253 (1952).
(g) Naidu, et al., J. Phys. D 3, 957 (1970).

Table 1.23

Values of W for oxygen for E/N > 57 × 10^{-17}Vcm^2

E/N (10^{-17}Vcm^2)	W (10^8cm/sec)		E/N (10^{-17}Vcm^2)	W (10^8cm/sec)		E/N (10^{-17}Vcm^2)	W (10^8cm/sec)	
60.7	0.113	(c)	159.1	0.227	(a)	404	0.41	(a)
75.5	0.130	(c)	175.2	0.237	(a)	439	0.41	(a)
90.9	0.145	(c)	189.1	0.256	(a)	453	0.46	(b)
92.8	0.169	(a)	197.0	0.259	(a)	499	0.45	(a)
98.8	0.176	(a)	204.3	0.272	(b)	516	0.43	(a)
105.9	0.162	(c)	204.9	0.275	(a)	547	0.49	(a)
106.7	0.181	(a)	219.8	0.278	(a)	561	0.47	(a)
113.7	0.187	(a)	224.9	0.288	(a)	672	0.58	(b)
121.5	0.194	(a)	233.7	0.292	(a)	698	0.55	(a)
121.7	0.178	(c)	249.5	0.30	(a)	803	0.64	(a)
126.1	0.198	(a)	259.6	0.32	(b)	1180	0.78	(b)
131.2	0.201	(a)	273.1	0.31	(a)	1973	1.03	(b)
135.6	0.192	(c)	288.9	0.31	(a)	2001	0.97	(b)
137.3	0.208	(a)	303	0.33	(a)	2885	1.18	(b)
144.3	0.213	(a)	332	0.40	(b)	3140	1.20	(b)
149.7	0.216	(a)	333	0.35	(a)	7106	1.82	(b)
150.3	0.203	(c)	349	0.37	(a)	1293	2.60	(b)
153.1	0.220	(a)	364	0.38	(a)	2239	3.01	(b)

Experimental:
(a) Frommhold, Fortschr. Physik 12, 597 (1964).
(b) Schlumbohm, Z. Physik 182, 317 (1965).
(c) Naidu, et al., J. Phys. D 3, 957 (1970).

Table 1.24

Values of W_M for oxygen

E/N (10^{-17} Vcm^2)	W_M (10^7 cm/sec)	E/N (10^{-17} Vcm^2)	W_M (10^7 cm/sec)	E/N (10^{-17} Vcm^2)	W_M (10^7 cm/sec)
1.067	0.062	12.70	0.41	28.73	0.56
1.281	0.106	14.36	0.42	40.8	0.73
1.502	0.134	14.78	0.43	42.0	0.75
2.533	0.203	15.14	0.43	42.6	0.75
3.84	0.242	15.38	0.43	51.0	0.87
3.93	0.250	15.53	0.43	53.6	0.85
6.26	0.31	18.03	0.44	70.0	1.12
6.44	0.31	18.69	0.46	99.2	1.48
7.33	0.33	18.84	0.47	118.9	1.72
9.00	0.36	20.33	0.48	119.6	1.76
9.45	0.37	23.60	0.51	137.7	1.92
11.41	0.39	23.69	0.53	156.5	1.15
11.86	0.40	25.09	0.54	174.6	2.35

Experimental:
All data taken from Brose, Phil. Mag. 50, 536 (1925).

Table 1.25(a)

Values of W in carbon monoxide at 300 K

E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)
0.00901	0.032	0.1529	0.50	0.472	0.77
0.01506	0.053	0.1990	0.61	0.556	0.76
0.0304	0.105	0.2462	0.69	0.630	0.76
0.0613	0.207	0.2971	0.74	0.810	0.76
0.0777	0.246	0.312	0.79	1.287	0.91
0.1236	0.41	0.387	0.78		

Experimental:
All data taken from Pack, et al., Phys. Rev. 127, 2084 (1962).

Table 1.25(b)

Values of W in carbon monoxide at 77 K

E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)
0.0450	0.093	0.2314	{0.40	1.566	1.04
0.0600	0.133		0.43	2.195	1.249
0.0761	0.158	0.312	0.50	3.15	1.44
0.0918	0.196	0.472	0.56	8.05	1.945
0.1224	0.244	0.614	0.67	10.73	1.99
0.1571	0.35	0.950	0.83	16.01	2.22
		1.090	0.88	26.06	2.71

Experimental:
All data taken from Pack, et al., Phys. Rev. 127, 2084 (1962).

Table 1.25(c)

Values of W in carbon monoxide at 195 K

E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)	E/N (10^{-17} Vcm^2)	W (10^6 cm/sec)
0.01487	0.040	0.1549	0.38	0.455	0.67
0.02248	0.061	0.2284	0.51	0.638	0.64
0.02962	0.078	0.301	0.58	1.573	0.96
0.0758	0.201	0.387	0.64		

Experimental:
All data taken from Pack, et al., Phys. Rev. 127, 2084 (1962).

Table 1.26

Values of W_M for carbon monoxide

E/N (10^{-17} Vcm^2)	W_M (10^7 cm/sec)	E/N (10^{-17} Vcm^2)	W_M (10^7 cm/sec)	E/N (10^{-17} Vcm^2)	W_M (10^7 cm/sec)
0.319	0.065	2.551	0.162	20.41	0.32
0.638	0.087	5.10	0.225	40.8	0.46
1.276	0.119	10.19	0.265	81.6	0.72
				163.3	1.44

Experimental:
All data taken from Skinker, et al., Phil. Mag. 46, 630 (1923).

Table 1.27

Values of W_M for nitric oxide

E/N (10^{-17} Vcm^2)	W_M (10^6 cm/sec)	E/N (10^{-17} Vcm^2)	W_M (10^6 cm/sec)	E/N (10^{-17} Vcm^2)	W_M (10^6 cm/sec)
1.280	2.02	14.99	6.0	31.9	6.7
2.377	2.39	16.09	6.1	33.7	6.8
4.21	2.98	17.28	6.3	36.1	7.0
5.85	3.5	18.10	6.3	38.7	7.2
7.04	3.9	19.29	6.4	41.7	
8.96	4.4	21.03	6.4	45.2	7.9
10.79	5.0	23.13	6.4	47.7	8.2
11.88	5.3	25.32	6.4	50.2	8.4
13.07	5.6	26.60	6.5	52.8	8.7
14.17	5.8	28.71	6.5	55.6	9.0
		30.7	6.6	59.5	9.3

Experimental:
All data taken from Bailey, et al., Phil. Mag. 17, 1169 (1934).

Table 1.28

Values of W for carbon dioxide for $E/N < 25 \times 10^{-17} Vcm^2$

E/N ($10^{-17} Vcm^2$)	W ($10^5 cm/sec$)		E/N ($10^{-17} Vcm^2$)	W ($10^5 cm/sec$)		E/N ($10^{-17} Vcm^2$)	W ($10^5 cm/sec$)	
0.0311	0.056	(a)	0.759	1.35	(b)	3.64	6.5	(b)
0.0594	0.115	(a)	0.910	1.62	(b)	4.55	8.2	(b)
0.1506	0.283	(a)	1.214	2.16	(b)	6.07	11.3	(b)
0.301	0.56	(a)	1.517	2.70	(b)	7.59	14.5	(b)
0.303	0.54	(b)	1.820	3.2	(b)	9.10	18.2	(b)
0.364	0.65	(b)	2.124	3.8	(b)	12.14	27.3	(b)
0.455	0.81	(b)	2.43	4.3	(b)	15.17	40	(b)
0.546	0.97	(b)	2.730	4.9	(b)	18.20	55	(b)
0.607	1.08	(b)	3.03	5.4	(b)	21.24	68	(b)

Experimental:

(a) Pack, et al., Phys. Rev. 127, 2084 (1962).

(b) Elford, Austr. J. Phys. 19, 629 (1966).

Table 1.29

Values of W for carbon dioxide for $E/N > 100 \times 10^{-17} Vcm^2$

E/N ($10^{-17} Vcm^2$)	W ($10^8 cm/sec$)		E/N ($10^{-17} Vcm^2$)	W ($10^8 cm/sec$)		E/N ($10^{-17} Vcm^2$)	W ($10^8 cm/sec$)	
114.4	0.134	(a)	909	0.46	(b)	3940	1.09	(b)
126.8	0.143	(a)	1212	0.55	(b)	4240	1.14	(b)
131.5	0.150	(a)	1516	0.62	(b)	4550	1.19	(b)
135.1	0.147	(a)	1819	0.69	(b)	4850	1.24	(b)
147.7	0.162	(a)	2122	0.76	(b)	5150	1.28	(b)
151.5	0.166	(b)	2425	0.82	(b)	5460	1.33	(b)
153.5	0.169	(a)	2728	0.88	(b)	5760	1.37	(b)
158.7	0.172	(a)	3030	0.94	(b)	6062	1.41	(b)
455	0.31	(b)	3330	0.99	(b)			
606	0.36	(b)	3640	1.04	(b)			

Experimental:

(a) Frommhold, Z. Physik 160, 554 (1960).

(b) Schlumbohm, Z. Physik 182, 317 (1965).

Table 1.30

Values of W for air for E/N < 9.5 × 10^{-17} Vcm^2

E/N (10^{-17}Vcm^2)	W (10^6cm/sec)	E/N (10^{-17}Vcm^2)	W (10^6cm/sec)	E/N (10^{-17}Vcm^2)	W (10^6cm/sec)
0.292	0.39 (1)	1.409	0.86 (1)	3.48	1.29 (1)
0.333	0.41 (1)	1.516	0.95 (b)	3.64	1.25 (a)
0.370	0.43 (1)	1.528	0.84 (a)	4.00	1.37 (1)
0.406	0.45 (1)	1.567	0.91 (1)	4.03	1.33 (a)
0.452	0.47 (1)	1.679	0.94 (1)	4.45	1.43 (1)
0.514	0.51 (1)	1.803	0.98 (1)	4.55	1.50 (b)
0.565	0.53 (1)	1.828	0.89 (a)		1.37 (a)
0.606	0.51 (a)	1.849	0.93 (a)	4.89	1.50 (1)
	0.61 (b)	1.932	1.02 (1)	4.92	1.42 (a)
0.619	0.56 (1)	2.099	1.05 (1)	5.10	1.46 (a)
0.673	0.58 (1)	2.125	0.99 (a)	5.43	1.58 (1)
0.740	0.61 (1)	2.333	1.10 (1)	5.83	1.56 (a)
0.820	0.65 (1)	2.370	1.05 (a)	6.03	1.67 (1)
0.882	0.67 (a)	2.449	1.10 (a)	6.06	1.68 (b)
0.912	0.68 (1)	2.529	1.14 (1)	6.55	1.70 (a)
1.014	0.71 (1)	2.716	1.17 (1)	6.70	1.77 (1)
1.140	0.76 (1)	3.30	1.25 (b)	7.53	1.88 (1)
1.143	0.76 (a)	3.05	1.17 (a)	8.43	1.91 (a)
1.297	0.82 (1)	3.090	1.23 (1)	8.87	2.06 (1)
				9.09	2.3 (b)

Experimental:
(a) Nielsen, et al., Phys. Rev. 51, 69 (1937).
(b) Hessenauer, Z. Physik 204, 142 (1967).
Theoretical:
(1) Heylen, Proc. Phys. Soc. (London) 79, 284 (1962).

Table 1.31

Values of W for air for E/N > 9.5 × 10^{-17} Vcm^2

E/N (10^{-17}Vcm^2)	W (10^7cm/sec)	E/N (10^{-17}Vcm^2)	W (10^7cm/sec)	E/N (10^{-17}Vcm^2)	W (10^7cm/sec)
9.98	0.222 (1)	43.3	0.73 (1)	152.2	1.67 (a)
11.51	0.244 (1)	47.5	0.78 (1)	160.6	1.89 (b)
12.76	0.264 (1)	52.8	0.86 (1)	167.2	1.85 (a)
13.87	0.283 (1)	56.6	0.90 (1)	171.6	1.94 (b)
15.42	0.31 (1)	62.2	0.97 (1)	183.1	1.94 (a)
16.94	0.34 (1)	67.6	1.04 (1)	189.7	2.11 (b)
18.58	0.37 (1)	75.0	1.12 (1)	197.2	2.04 (a)
20.18	0.40 (1)	82.4	1.20 (1)	199.8	2.19 (b)
22.18	0.43 (1)	90.6	1.28 (1)	223.0	2.39 (b)
24.04	0.46 (1)	103.0	1.40 (1)	233.5	2.48 (b)
26.42	0.50 (1)	106.3	1.25 (a)	234.2	2.32 (a)
29.38	0.54 (1)	114.2	1.30 (a)	241.6	2.52 (b)
33.4	0.60 (1)	122.1	1.31 (a)	258.0	2.69 (b)
36.3	0.64 (1)	137.2	1.51 (a)	270.6	2.81 (b)
39.8	0.69 (1)	140.8	1.62 (b)	274.9	2.77 (a)
				295.9	2.99 (b)

Experimental:
(a) Frommhold, Fortschr. Physik 12, 597 (1964).
(b) Ryzko, Proc. Phys. Soc. (London) 85, 1283 (1965).
Theoretical:
(1) Heylen, Proc. Phys. Soc. (London) 79, 284 (1962).

Table 1.32

Values of W_M for air

E/N (10^{-17}Vcm^2)	W_M (10^7cm/sec)	E/N (10^{-17}Vcm^2)	W_M (10^7cm/sec)	E/N (10^{-17}Vcm^2)	W_M (10^7cm/sec)
0.589	0.0277 (a)	10.02	0.231 (a)	33.2	0.56 (a)
1.178	0.078 (a)	10.80	0.227 (a)	44.3	0.73 (b)
1.218	0.102 (b)	11.81	0.295 (b)	49.1	0.77 (a)
1.473	0.068 (a)	12.67	0.256 (a)	49.5	0.76 (a)
2.160	0.083 (a)	13.45	0.288 (a)	59.2	0.89 (b)
2.624	0.136 (b)	14.51	0.302 (a)	60.5	0.95 (a)
3.04	0.135 (a)	16.20	0.32 (a)	62.6	0.94 (a)
3.34	0.119 (a)	16.99	0.32 (a)	65.3	0.88 (a)
4.81	0.158 (a)	17.81	0.38 (b)	65.6	0.95 (a)
5.72	0.198 (b)	18.36	0.36 (a)	68.9	0.95 (a)
5.96	0.175 (a)	19.15	0.36 (a)	74.0	1.04 (b)
5.99	0.174 (a)	23.52	0.47 (b)	95.5	1.30 (a)
7.37	0.197 (a)	24.75	0.44 (a)	126.9	1.64 (a)
8.05	0.212 (a)	29.52	0.55 (b)	131.8	1.53 (a)
8.15	0.196 (a)	30.1	0.53 (a)	193.4	1.99 (a)
8.72	0.246 (b)	31.2	0.54 (a)	256.3	2.46 (a)
8.94	0.217 (a)	32.1	0.55 (a)	468	3.55 (a)
				619	4.49 (a)

Experimental:
(a) Townsend, et al., Proc. Roy. Soc. (London) Ser. A 88, 336 (1913).
(b) Huxley, et al., Proc. Roy. Soc. (London) Ser. A 196, 402 (1949).

3.2. (Diffusion Coefficient)/Mobility

As an electron swarm drifts with a velocity W under the influence of an electric field E, it also diffuses due to the agitational velocity of the electrons. The diffusion is characterized by a diffusion coefficient D defined by the equation

$$j = -D\nabla n, \tag{4}$$

where j is the number of electrons flowing normally across unit area per second due to the density gradient of the electrons. At very low electric field strengths, the diffusion is symmetric and D is a constant independent of direction. As the electric field strength increases from very low values, the diffusion becomes asymmetric and the diffusion coefficient becomes a tensor, with components D_T and D_L transverse to and along the direction of E, respectively.

A useful and widely measured parameter of an electron swarm is the ratio W/D_T, because

i) it is directly related to the mean energy of the swarm;
ii) it can be related to the collision cross section (see eq (8)), and
iii) when taken together with measured values of W, it gives values of D_T, which is a difficult parameter to measure directly.

The equation relating W/D_T to mean energy may be written as

$$W/D_T = (2F/3\mathrm{k})(Ee/kT), \tag{5}$$

where k is Boltzmann's constant, T is the absolute temperature and, k is the so-called Townsend energy factor which is defined as the ratio of the mean energy of the electrons to that of gas atoms at 15 °C, and F is a dimensionless constant that depends on the energy distribution (see L. G. H. Huxley and R. W. Crompton, in *Atomic and Molecular Processes*, D. R. Bates, ed., Academic Press, New York, 1962, pp. 336–73); F takes the value 1.5 for a Maxwellian distribution and 1.312 for a Druyvesteyn distribution.

If E is in V cm^{-1}, the other quantities in cgs units and $T=288$ K is adopted as a standard temperature, eq (5) becomes

$$W/D_T = 40.3\ (E/\mathrm{k}_1), \tag{6}$$

where

$$\mathrm{k}_1 = 3\mathrm{k}/2F.$$

In order to relate W/D_T to the collision cross section, the expression

$$D_T = (4\pi/3N)\int_0^\infty (c^3/q_m) f\,dc, \qquad (7)$$

which relates the diffusion coefficient to atomic parameters, may be used in combination with eq (1) to give

$$D_T E/W = -(m/e)\frac{\int_0^\infty (c^3/q_m) f\,dc}{\int_0^\infty (c^2/q_m)(df/dc)\,dc}, \qquad (8)$$

which has been used [see, e.g., 1062, 2433] to obtain information about q_m from data on electron swarms.

Experimentally, W/D_T is determined by means of the Townsend method (see J. S. Townsend, Proc. Roy. Soc. **A80**, 207, 1908; **A81**, 464, 1908) in which the distribution of the electron current over a given plane perpendicular to the direction of drift of an electron swarm originating at a point or line source is measured. There are considerable difficulties in the analysis of such measurements, but recent discussion (Crompton, Australian J. Phys. **25**, 409, 1972) has shown that despite these difficulties the values obtained are valid in most cases.

The parameter determined is W/D_T but as can be seen from eq (6) this quantity depends on N as well as on E/N. Thus the results of the experiments are usually given in terms of the parameter

$$D_T E/W = D_T/\mu,$$

where $\mu = W/E$ is the electron mobility. Alternatively, the results may be expressed in terms of

$$\epsilon_k = e(D_T/\mu),$$

which is usually known [260] as the "characteristic energy," because, as can be seen from eq (5), it is related to the mean energy. Both ϵ_k and D_T/μ are functions only of E/N; the value of ϵ_k in electron volts is, of course, the same as that of D_T/μ in volts.

Recently, measurements have also been made [see, e.g., 3313] of W/D_L (where D_L is the longitudinal diffusion coefficient in a direction parallel to the electric field) using time-of-flight methods.

Values of D_T/μ for all the gases with which this survey is concerned and of D_L/μ where available are given in the following sub-sections.

3.2.a. Values of D_T/μ and of D_L/μ—Helium

A critical examination of the Townsend method by Crompton, Elford, and Jory [2433; see also 1622 and 1438] has shown that it is possible, provided sufficient care is taken particularly in relation to field uniformity, to obtain values of D_T/μ with an error of less than 1 percent. Their results for helium [2433] are shown in figure 2.1(a). Also shown are the earlier experimental data [1036, 201], some of which [1036] required an empirical correction for geometrical distortion. Both Crompton et al. [2433] and Frost and Phelps [1062] obtained theoretical values by using the value of q_m discussed in section 3.1.a and the agreement obtained with their experimental values is shown in figure 2.1(b). As shown in figure 2.2, there is also good agreement between experimental [1036] and theoretical [1062] values of D_T/μ obtained at a temperature of 77 K. Sets of values of D_T/μ both at ambient temperature and 77 K are given in table 2.1.

There have also been recent measurements [3313] of D_L/μ for helium using a time-of-flight method and the values obtained are given in figure 2.1(a) and table 2.2. (The temperature to which the values of E/p given in this paper correspond is not clear, but later work [see 5135] shows it was probably 27 °C so this temperature was assumed here and wherever it is referred to in the rest of this section.) Also shown in figure 2.1(a) are the theoretical values obtained by Lowke and Parker [4052] using the values of q_m obtained in [2433]. There is agreement to within about 15 percent between theory and experiment.

3.2.b. Values of D_T/μ—Neon

There are very few data available for D_T/μ for neon. The only experimental measurements are those of Bailey [2280] on neon containing 1 percent helium. These results are shown in figure 2.3 together with the available theoretical values [273, 2250] which were obtained using the energy distribution of [1388] and various assumed cross sections. Using values of the momentum transfer cross section obtained from drift velocity measurements, Robertson [4862] calculated values of D_T/μ which are stated to be about 20 percent below Bailey's values. Since Robertson finds the values of D_T/μ very sensitive to nitrogen impurities he suggests that molecular impurities in Bailey's gas samples might account for the difference.

There are no experimental or theoretical values of D_L/μ available for neon.

3.2.c. Values of D_T/μ and D_L/μ—Argon

There have been two experimental investigations of D_T/μ for argon, the early results of Townsend and Bailey [199] covering the range $3\times10^{-18} < E/N < 6\times10^{-16}$ V cm² at room temperature, and the more recent data of Warren and Parker [1036] in the range $4.5\times10^{-21} < E/N < 1.3\times10^{-18}$ V cm² at temperatures of 77 K and 87 K. Both sets of data are shown in figure 2.4 and tabulated in table 2.3. The theoretical results of Engelhardt and Phelps [292] calculated using the values of q_m discussed in section 3.1.e are also shown in figure 2.4. There is good agreement between theory and experiment except in the range of E/N from about 3×10^{-18} to 10^{-17} V cm^2.

Recent theoretical values of D_L/μ for argon at a temperature of 77 K, calculated [4052] using the above mentioned cross sections [292] and also the cross sections obtained by Golden (Phys. Rev. **151**, 48, 1966), are shown in figure 2.5. It can be seen that the results differ for values of E/N between about 10^{-20} and 10^{-19} V cm^2, but agree at higher values of E/N where they lie below the recent experimental results [3313] obtained at ambient temperatures. These experimental and theoretical data are given in table 2.4.

At higher values of E/N, Wagner [4971], from observation of the drift and diffusion of pulsed electron avalanches, gave values for $D_T/\mu \simeq 6.3 \pm 1.1$ for $72 \times 10^{-17} < E/N < 136 \times 10^{-17}$ V cm^2.

3.2.d. Values of D_T/μ and D_L/μ—Krypton and Xenon

The only available experimental result for D/μ for krypton and xenon is a value of about 3.1 ± 0.9 V for D_T/μ for E/N in the range from 120×10^{-17} to 275×10^{-17} V cm^2 obtained [4971] from observations on pulsed avalanches.

At lower values of E/N ($< 3 \times 10^{-17}$ V cm^2) theoretical values of D_T/μ were obtained by Frost and Phelps [1062] and of D_L/μ by Lowke and Parker [4052] using the cross sections mentioned in section 3.1.g. These theoretical values are shown in figure 2.6 and given in tables 2.5 and 2.6.

3.2.e. Values of D_T/μ and D_L/μ—Hydrogen

There have been a relatively large number of investigations of D/μ for hydrogen and the results at room temperature may most conveniently be considered in two regions of E/N, above and below $E/N = 10^{-16}$ V cm^2. The results in the region of E/N below 10^{-16} V cm^2 are shown in figure 2.7. The most recent data [2992] for D_T/μ are accurate to within ± 1 percent; at the higher values of E/N, these data agree with the earlier data [1438, 689, 352] obtained in the same laboratory and at the lower values of E/N, are regarded as more accurate. Thus to avoid confusion they are the only results of Crompton's group shown on the figure. It can be seen that all the experimental results [2992, 736, 195] for D_T/μ shown in figure 2.7 are in good agreement at the higher values of E/N, but that the results of [736] increasingly diverge from the others as E/N decreases. Theoretical values [181] calculated using the cross sections referred to in section 3.1.h are in good agreement with the recent experimental data and are shown in figure 2.7. The numerical values given in table 2.7 for $E/N < 7 \times 10^{-17}$ V cm^2 are those of [2992].

The recent experimental values [3313] of D_L/μ for hydrogen are shown in figure 2.7, together with the recent theoretical values [4052] obtained using the same cross sections as those used for the calculation of D_T/μ. The experimental values of D_L/μ are also given in table 2.8.

Results for D_T/μ and D_L/μ at values of $E/N > 10^{-16}$ V cm^2 are shown in figure 2.8. Ionization processes begin to become important in hydrogen when $E/N > 5.6 \times 10^{-16}$ V cm^2. Some of the results [1437, 1778, 5230, 5234] were obtained using an analysis taking ionization into account, whereas no account was taken of ionization in [195] and an unspecified correction for ionization was made in [3303]. The cross sections which gave theoretical ionization coefficients in good agreement with experiment (see sec. 3.7.b(i)) give theoretical values [260] of D_T/μ much higher (up to 40 percent greater) than the experimental values and are not shown. The experimental values of D_T/μ obtained taking ionization into account are included in table 2.7.

Schlumbohm [1625] determined the pulse shape of electron avalanches in a uniform field electrode system, so that his values of D/μ, which are also shown in figure 2.8, represent values of D_L/μ.

The two sets [2992, 1036] of available experimental data for D_T/μ at 77 K are in good agreement with one another, although that given in [1036] is based on an empirical calibration of the apparatus used. The values are shown, together with the theoretical values [260] for this temperature, in figure 2.9. A set of numerical values is given in table 2.9.

3.2.f. Values of D_T/μ and D_L/μ—Nitrogen

It is convenient to consider the results for D_T/μ obtained for nitrogen in two ranges, above and below a value of E/N of about 14×10^{-17} V cm^2. The results for $E/N < 14 \times 10^{-17}$ V cm^2 at ambient temperatures are shown in figure 2.10. The most recent results [689 and 1429] have an estimated error of less than 1 percent and these are tabulated in table 2.10. Small differences between these results and some of the earlier data [736 and 352] are ascribable to differences in purity of the gas. Commercial tank nitrogen with an impurity level of about 5 in 10^3 was used in the earlier work compared with samples containing impurities of a few ppm in the later experiments.

Also shown in figure 2.10 are the theoretical values obtained [181, 4052] by numerical solution of the Boltzmann equation.

The most recent experimental data [3303] for D_T/μ at values of $E/N > 14 \times 10^{-17}$ V cm^2 show that the results for spectroscopically pure nitrogen agree with those for tank nitrogen in this range. These results are shown, together with earlier experimental data and theoretically computed values [4052] in figure 2.11. The experimental data are also given in table 2.10.

There are also both experimental [1036] and theoretical [218] results available at 77 K for the low E/N range. These are shown in figure 2.12 and a set of numerical values tabulated in table 2.11.

There are two sets of experimental data [1833, 3313] available for D_L/μ for values of $E/N < 14 \times 10^{-17}$ V cm^2 at room temperature and these are given in figure 2.13 where they are compared with theoretical results [4052] obtained by numerical integration of the Boltzmann equation.

For higher values of E/N there is only one set of experimental data [1625] available and these results are compared with theoretical values [5233] obtained by Monte Carlo methods in figure 2.14 (a temperature of 0 °C has been assumed in reducing the values of E/p given in this theoretical paper to E/N). The theoretical values obtained from integration of the Boltzmann equation [4052] for values of $E/N > 14 \times 10^{-17}$ V cm^2 are also shown in figure 2.14.

Table 2.12 gives a set of numerical values for D_L/μ for the whole range investigated.

3.2.g. Values of D_T/μ and D_L/μ—Oxygen

The available data for D_T/μ for oxygen are given in figure 2.15 and show that the more recent results [649, 1269, 5226] which have a quoted error of less than about 3 percent lie considerably above the early values [195, 2089] for $E/N > 5 \times 10^{-17}$ V cm^2. In an attempt to overcome some of the difficulties experienced in obtaining values of D_T/μ for electrons in the presence of negative ions, measurements have also recently been made [4901] in oxygen containing 1.7 percent hydrogen. The presence of the hydrogen rapidly removes O^- ions by an associative detachment reaction. These results for D_T/μ are also shown in figure 2.15 and can be seen to be in good agreement with the recent determinations in oxygen alone.

It has also been shown [2553] that a self-consistent set of values of the cross sections involved can be found that gives theoretical values of D_T/μ in good agreement with the recent experimental values. These theoretical values are also shown in figure 2.15.

A set of values of D_T/μ throughout the range of E/N investigated is given in table 2.13.

Experimental results for D_L/μ at very low values of E/N have recently been obtained using the drift-dwell-drift method (see section 3.3.a). These values are shown in figure 2.16 where they are compared with theoretical values [4052] which have been obtained over the range $10^{-18} < E/N < 10^{-15}$ V cm^2 using numerical integration of the Boltzmann equation. The disagreement between experimental and theoretical values suggests that some revision of the cross sections used in the theoretical calculations is necessary.

Schlumbohm [1625] obtained values of D/μ from investigations of avalanche shape at relatively high values of $E/N > 10^{-15}$ V cm^2. This type of experiment also gives values of D_L/μ and the results are shown in figure 2.17.

A composite set of tabulated values of D_L/μ for oxygen is given in table 2.14.

3.2.h. Values of D_T/μ and of D_L/μ—Carbon Monoxide

The only data at room temperature (unspecified) available for carbon monoxide are those of Skinker and White [200] for D_T/μ shown in figure 2.18. Also shown in figure 2.18 are the more recent results of Warren and Parker [1036] which were obtained at a temperature of 77 K using an apparatus that required empirical calibration because of slight field distortions. The theoretical values obtained for 77 K by Hake and Phelps [2553] and for 293 K by Lowke [4052] using the cross sections of Hake and Phelps are also given in figure 2.18 and can be seen to be in good agreement with the experimental values.

Sets of values of D_T/μ at room temperature and at 77 K are given in tables 2.15(a) and (b), respectively.

There is one set of experimental data [3313] available for D_L/μ. This was obtained at 293 K and is shown together with theoretical values [4052], obtained at both 293 K and 77 K, in figure 2.19.

Sets of values of D_L/μ are tabulated in tables 2.16(a) and (b) for temperatures of 293 K and 77 K, respectively.

3.2.i. Values of D_T/μ—Nitric Oxide

The only published data on D/μ available for nitric oxide are the early experimental results of Skinker and White [200] and of Bailey and Somerville [2385] for D_T/μ. Although, as can be seen from figure 2.20, there is fair agreement between the two sets of data, it should be noted that the results of Skinker and White showed a marked dependence of D_T/μ on pressure, especially at the low values of E/N, probably because of the formation of negative ions.

3.2.j. Values of D_T/μ and D_L/μ—Carbon Dioxide

Measurements of D_T/μ for carbon dioxide have been made over the range $5.6 \times 10^{-19} < E/N < 1.4 \times 10^{-15}$ V cm^2. Recent work [2140] has shown experimentally that below values of E/N of about 14×10^{-17} V cm^2 attachment has negligible influence on the results obtained. Several sets of data [159, 198, 736, 1036, and 2140] have been obtained in this range, but only those of Rees [2140] and of Warren and Parker [1036] extrapolated approximately to the expected value of D_{th}/μ (see 3.3) at low values of E/N and these results are shown in figure 2.21 and given in table 2.17.

At higher values of E/N, it was shown that under the experimental conditions used in [2140] the effect of attachment continued to be negligible up to a value of E/N of about 56×10^{-17} V cm^2, and the various sets of results [2140, 1036, 198, 159] (the data for D_T/μ ascribed to [159] are actually given in Healey and Reed, *The Behavior of Slow Electrons in Gases*, 1941, p. 98) are seen in figure 2.22 to be in good agreement in this region.

At values of E/N greater than about 56×10^{-17} V cm^2, the results obtained in [2140] showed that processes of both attachment and ionization become significant and that values of ionization coefficients and attachment coefficients are required for the analysis of the results. As a result, the values of D_T/μ are not accurately established in this region. The results of [2140] given in figure 2.22 were obtained using an expression that took ionization but not attachment into account. The magnitude of the further correction required for attachment is uncertain, because values for the attachment coefficient are not accurately known. The values of D_T/μ at the higher values of E/N obtained in [2140] and given in figure 2.22 are probably too low by an amount varying between 4 percent and 9 percent depending on the values used for the attachment coefficient. As can be seen from figure 2.22, the data of [198], in which there is no discussion of ionization and attachment processes, are somewhat lower at these higher values of E/N.

The variation of D_T/μ with temperature was investigated experimentally by Warren and Parker [1036] and the results are shown in figure 2.23 where it can be seen that they are in good agreement with results calculated by Hake and Phelps [2553] using a self-consistent set of collision cross sections.

Sets of numerical values of D_T/μ at ambient temperatures and 195 K are given in tables 2.17(a) and (b), respectively.

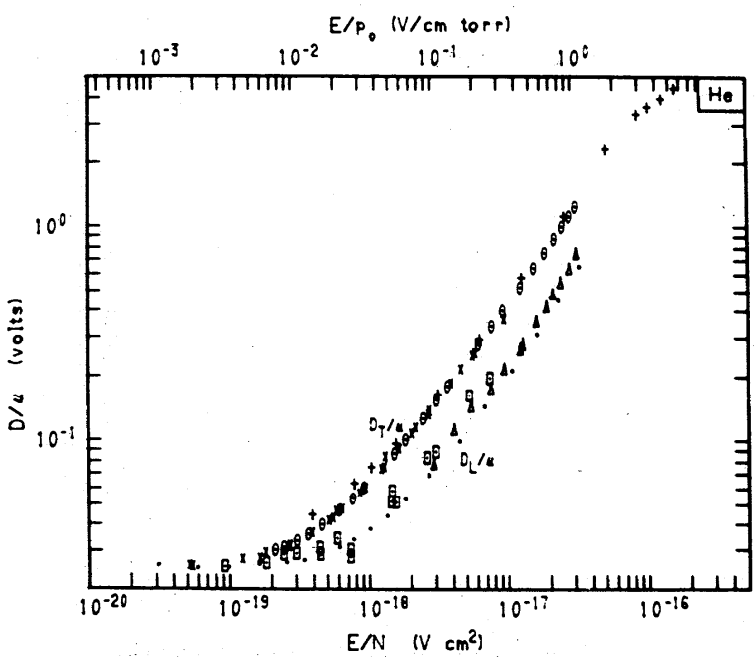
At relatively low values of $E/N < 10^{-15}$ V cm^2 there exists one published set of theoretical values [4052] of D_L/μ for CO_2 and these are compared in figure 2.24 with the experimental data [1833, 3313] which are available over a more limited range.

The only values of D_L/μ at high values of $E/N > 10^{-15}$ V cm^2 in carbon dioxide are those obtained by Schlumbohm [1625] from the analysis of the arrival times of electrons in an avalanche and these values are shown in figure 2.25. Table 2.18 gives a set of values of D_L/μ in CO_2.

3.2.k. Values of D_T/μ—Air

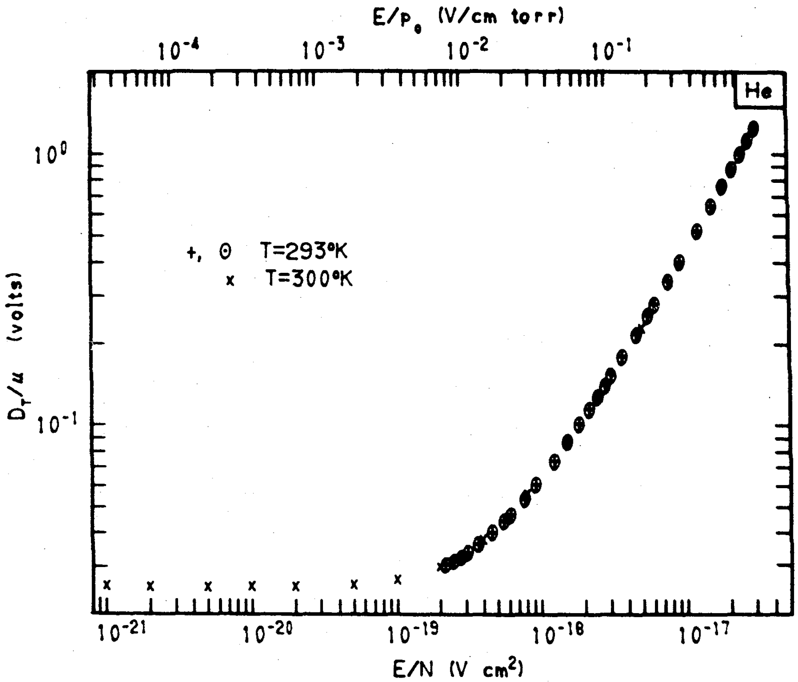
Recent values [2813, 2097] of D_T/μ with an estimated error of ±2 percent, obtained for dry air, from which CO_2 had been removed, are given in figure 2.26 and table 2.19. (In the region of overlap both sets of results agree and for clarity only those of [2097] are included in the figure.) These results are in good agreement with the later results of Rao [5247] and the early work of Bailey [1332] (not shown) if the temperature in the latter work is assumed to be 15 °C. As can be seen from figure 2.26, Townsend and Tizard's [2104] early results for dry air lie considerably below the recent values, possibly because the CO_2, which is expected to reduce the mean energy of the electrons, was not removed in this case. Above E/N of about 10^{-16} V cm^2 ionization becomes significant and may have affected the results of [2104].

There are no published theoretical values of D_T/μ available. Neither are there any published data for D_L/μ.



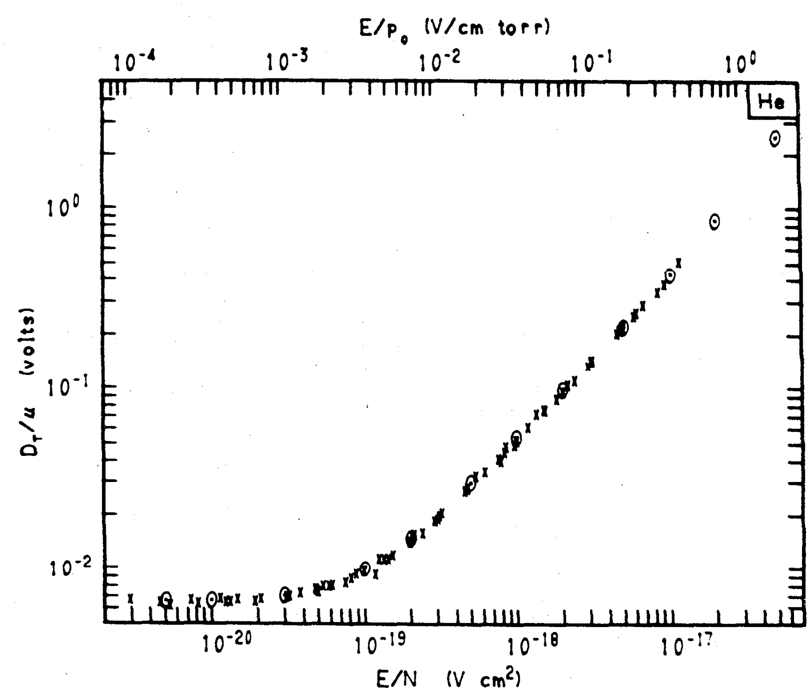
Experimental: Δ Wagner(3313); ⊡ Crompton (as given in Lowke(4052)); ⊖ Crompton(2433); x Warren(1036); + Townsend(201).
Theoretical: • Lowke(4052).

FIGURE 2.1(a). D_T/μ and D_L/μ as functions of E/N for helium at ambient temperature.



Experimental: + Crompton(2433).
Theoretical: x Frost(1062); ⊙ Crompton(2433)

FIGURE 2.1(b). Comparison of experimental and theoretical values of D_T/μ for helium at ambient temperatures.



Experimental: x Warren(1036).
Theoretical: ⊙ Frost(1062).

FIGURE 2.2. D_T/μ as a function of E/N in helium at 77 K.

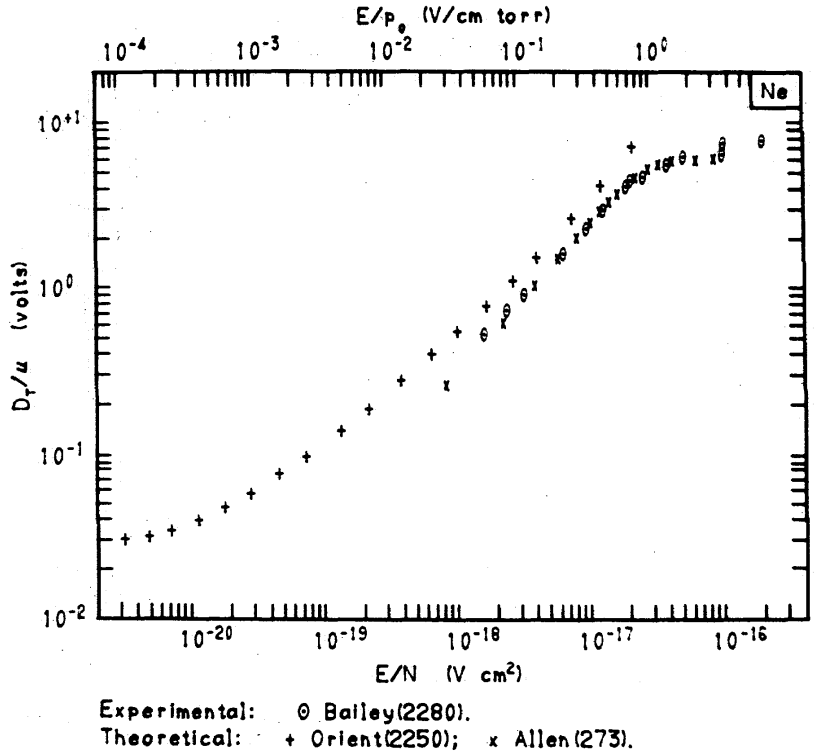


FIGURE 2.3. D_T/μ, E/N for neon. (The experimental results are for neon containing 1 percent helium. The temperature to which the values of E/p correspond in [273] is assumed to be 14 °C.)

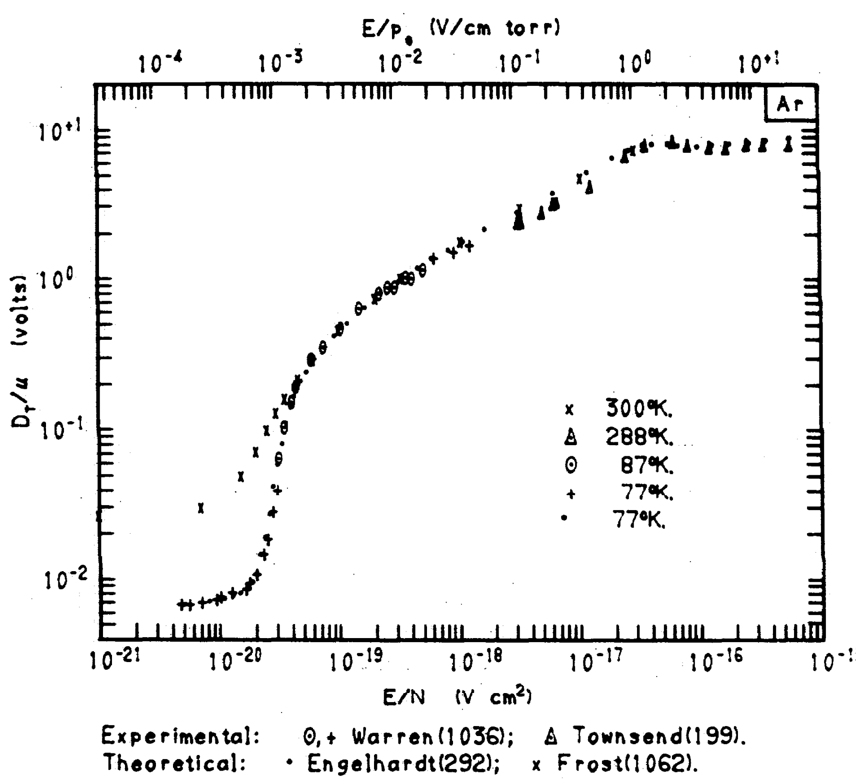
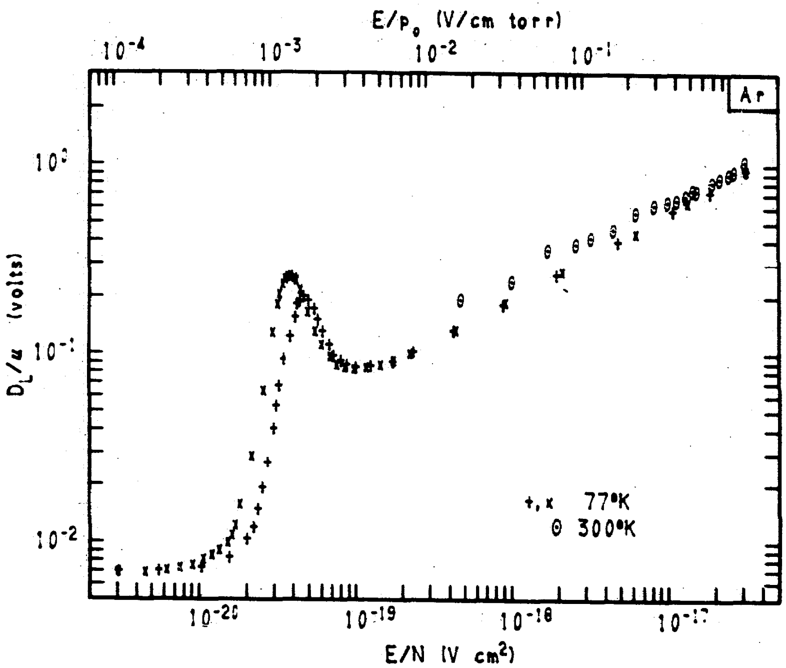
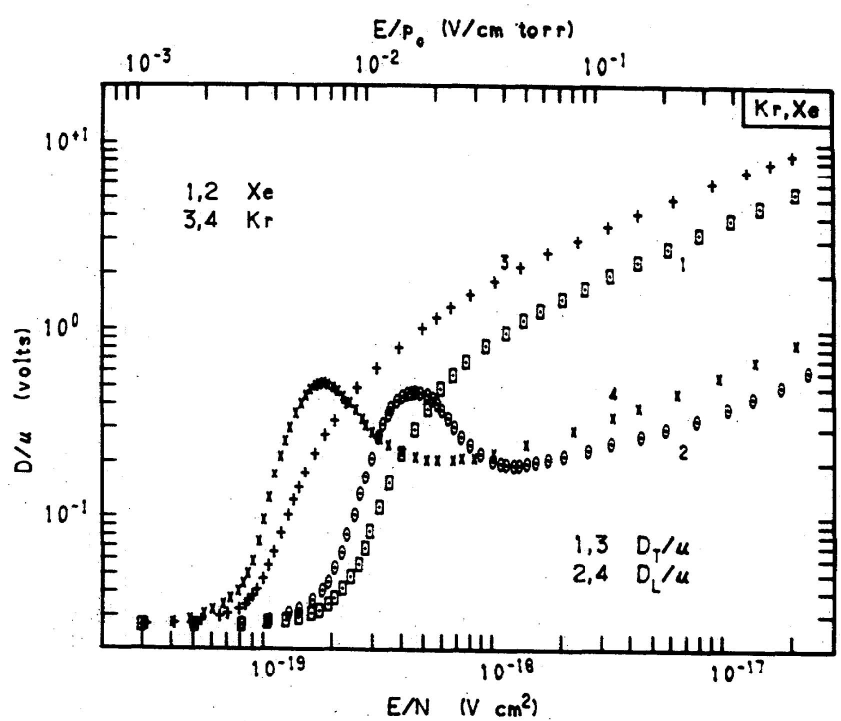


FIGURE 2.4. D_T/μ, E/N for argon at various temperatures.



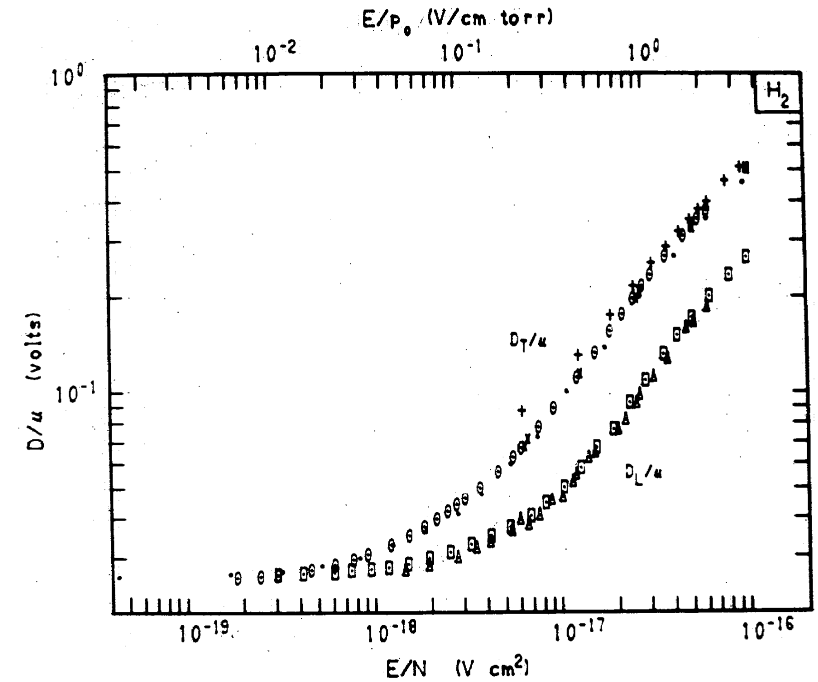
Experimental: θ Wagner(3313).
Theoretical: x, + Lowke(4052), using different values of q_m (see text).

FIGURE 2.5. D_L/μ, E/N for argon.



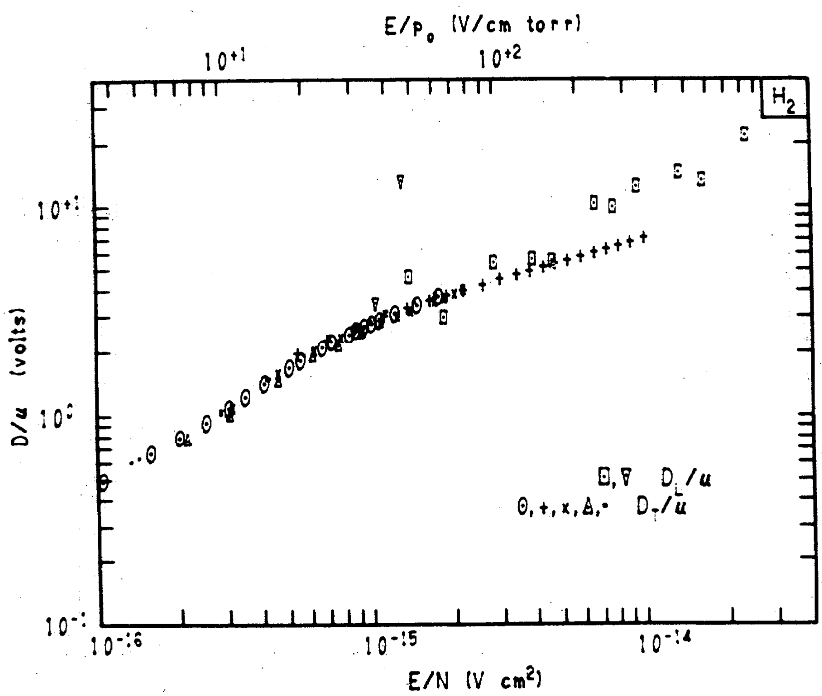
Theoretical: 1,3 Frost(1062); 2,4 Lowke(4052).

FIGURE 2.6. Theoretical values of D_T/μ and D_L/μ for krypton and xenon.



Experimental: ⊖ Crompton(2992); + Cochran(736);
x Townsend(195); Δ Wagner(3313).
Theoretical: • Frost(181); ⊡ Lowke(4052).

FIGURE 2.7. D_T/μ and D_L/μ as functions of E/N for hydrogen at room temperature for $E/N < 10^{-16}$ V cm².



Experimental: ⊖ Townsend(195); +Lawson(1778);
x Crompton(1437); Δ Naidu(3303); ⊡ Schlumbohm(1625);
∇ Breare(3788); • Virr(5050),(5230).

FIGURE 2.8. D_T/μ and D_L/μ as functions of E/N for hydrogen at room temperature for $E/N > 10^{-16}$ V cm².

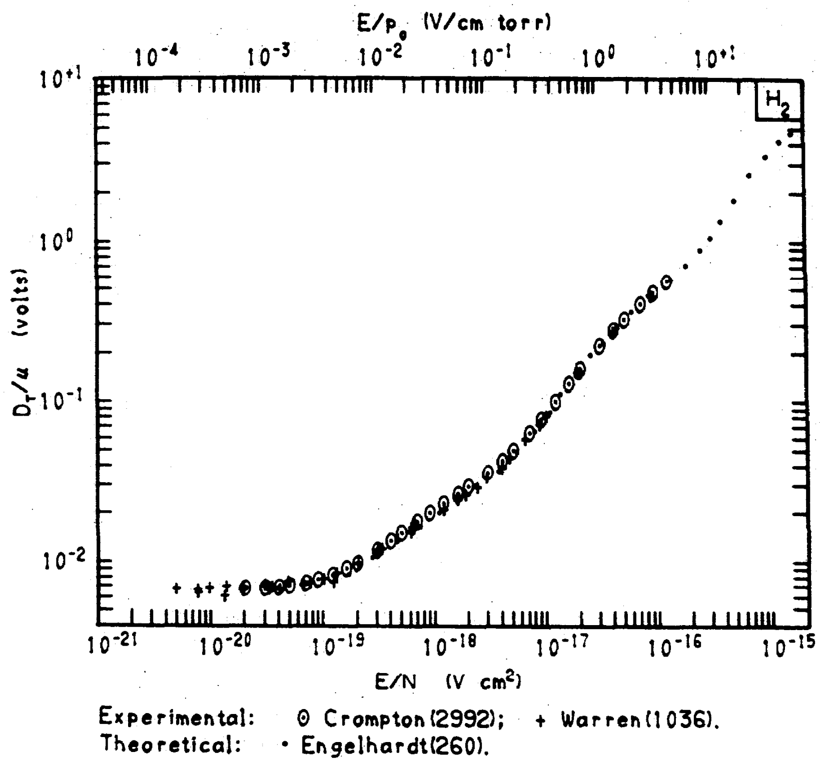


FIGURE 2.9. D_T/μ as a function of E/N for hydrogen at a temperature of 77 K.

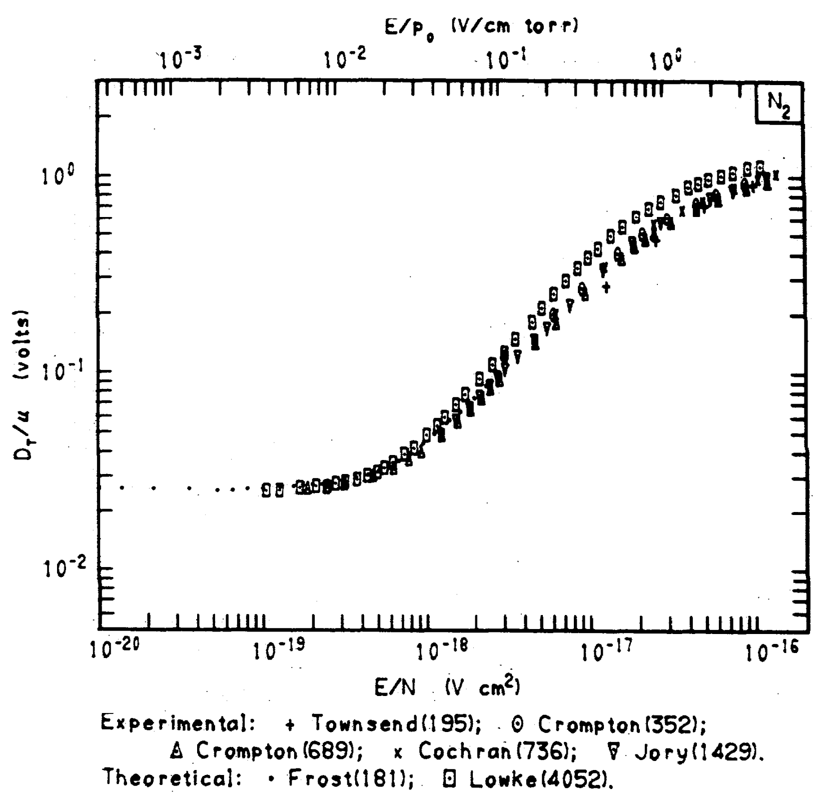


FIGURE 2.10. D_T/μ, E/N for nitrogen for $E/N < 14.1 \times 10^{-17}$ V cm² at ambient temperature.

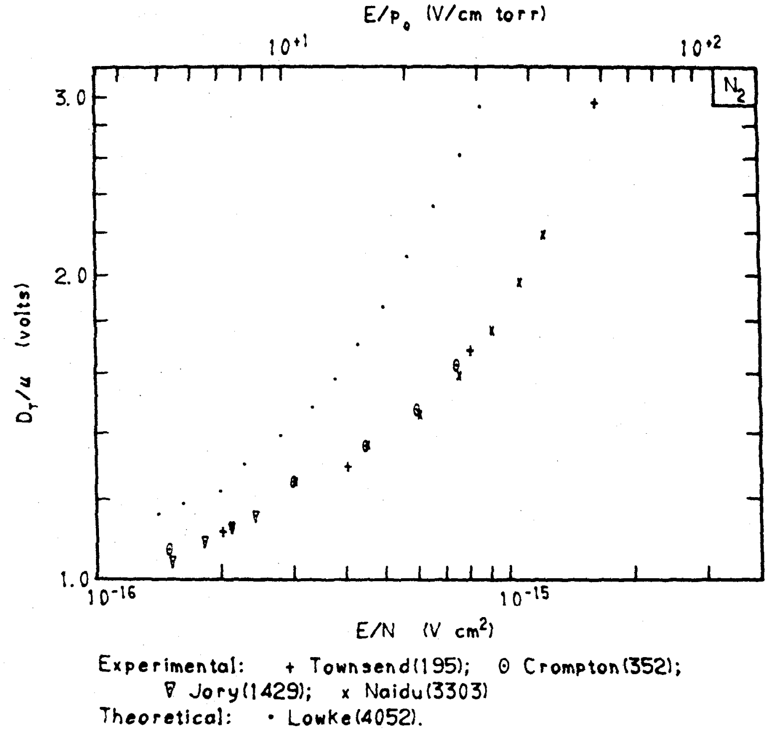


FIGURE 2.11. D_T/μ, E/N for N_2 for $E/N > 14\times10^{-17}$ V cm^2 at ambient temperature.

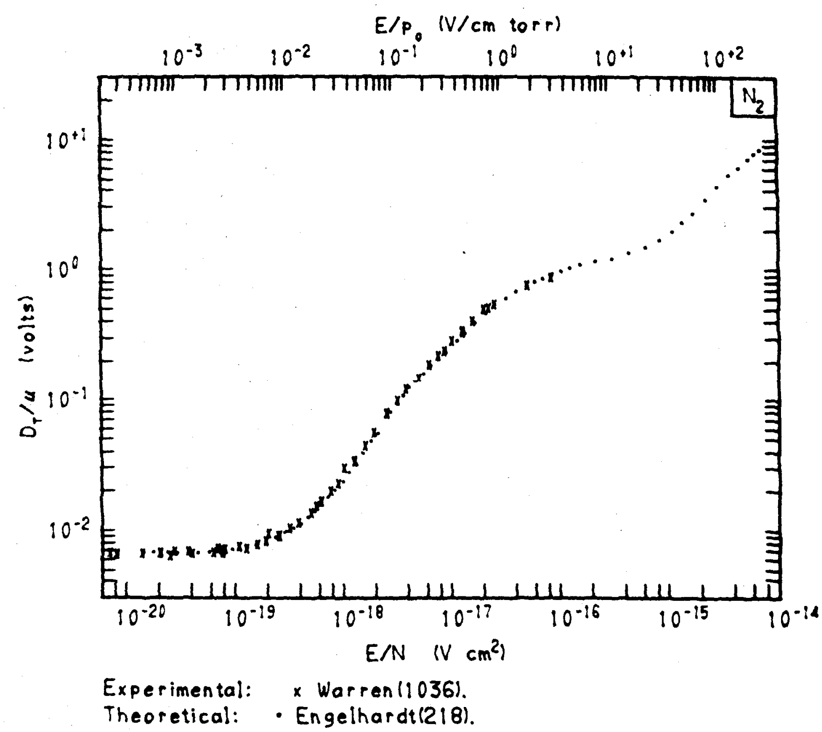
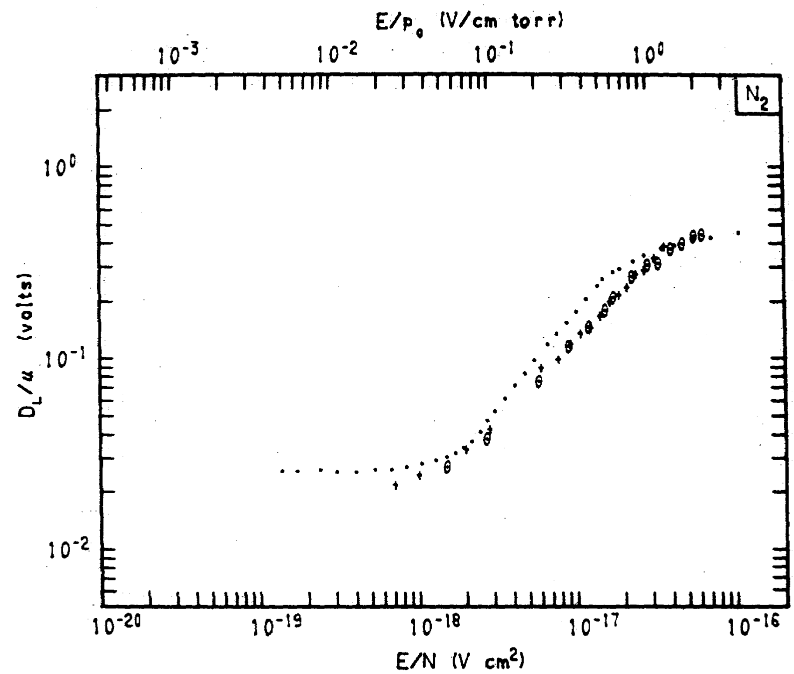
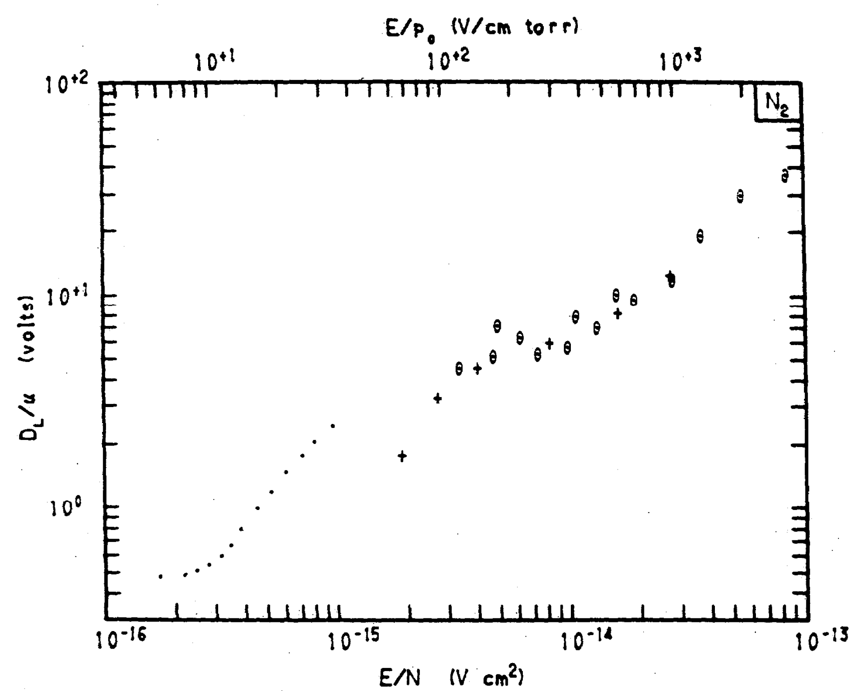


FIGURE 2.12. D_T/μ, E/N for nitrogen at a temperature of 77 K.



Experimental: + Fink(1833); ⊖ Wagner(3313).
Theoretical: • Lowke(4052).

FIGURE 2.13. D_L/μ, E/N for nitrogen for $E/N < 14 \times 10^{-17}$ V cm².



Experimental: ⊖ Schlumbohm(1625).
Theoretical: • Lowke(4052); + Kline(5233).

FIGURE 2.14. D_L/μ, E/N for nitrogen for $E/N > 14 \times 10^{-17}$ V cm².

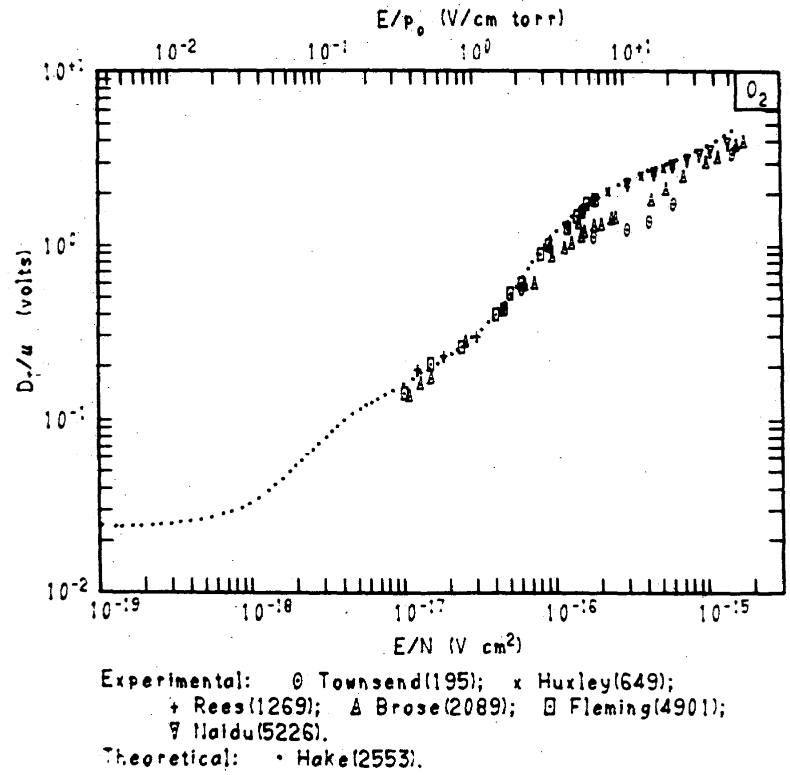


FIGURE 2.15. D_T/μ, E/N for oxygen.

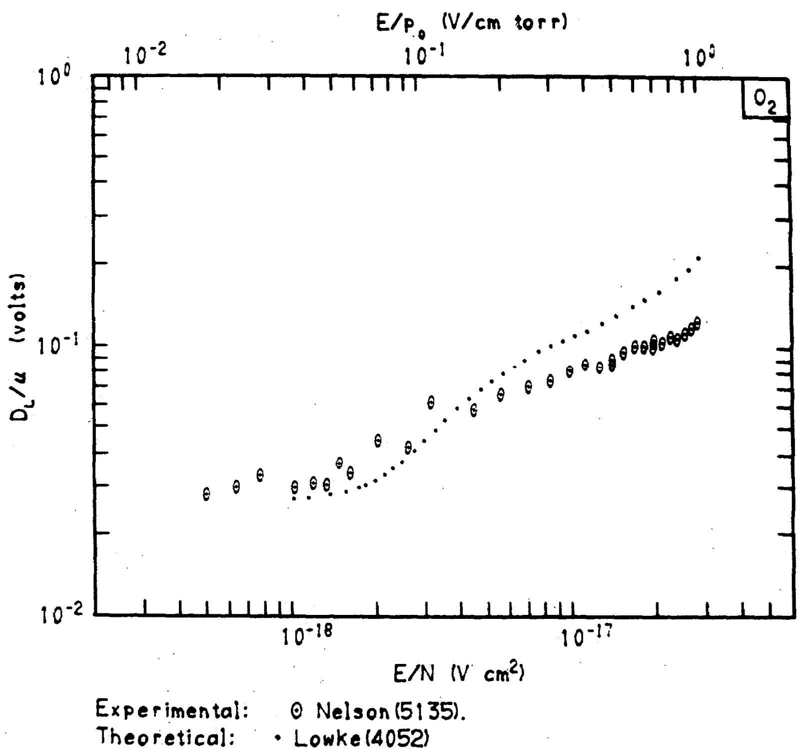


FIGURE 2.16. D_L/μ, E/N for oxygen for $E/N < 3 \times 10^{-17}$ V cm^2.

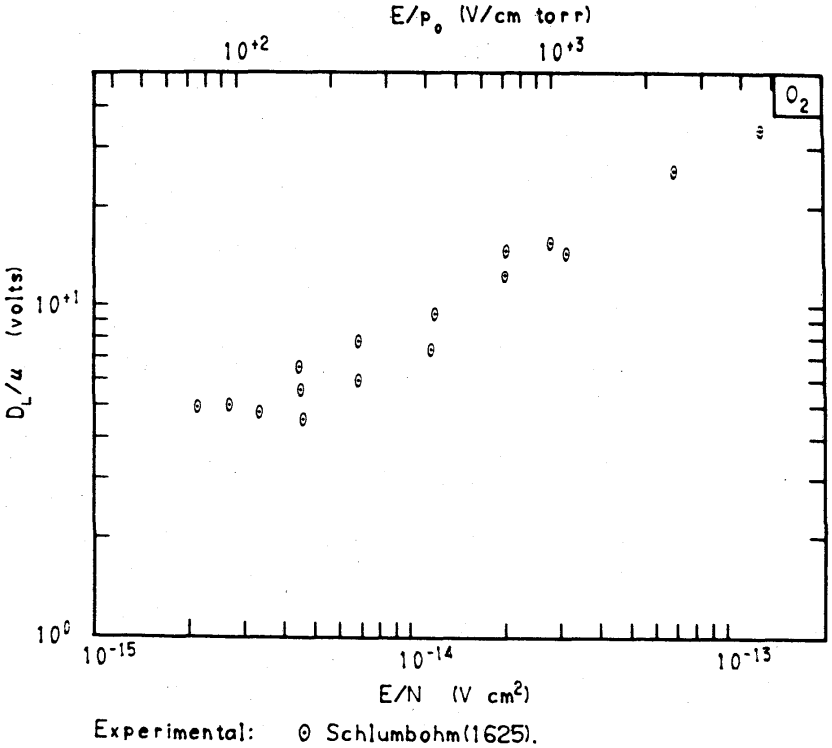


FIGURE 2.17. Experimental D_L/μ, E/N for oxygen for $E/N > 10^{-15}$ V cm².

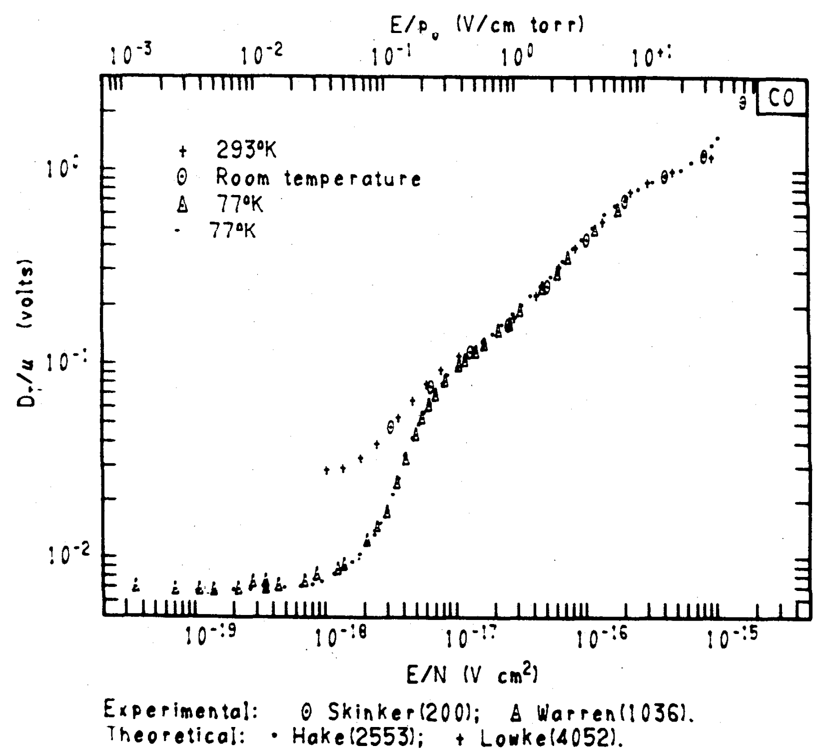


FIGURE 2.18. D_T/μ, E/N for carbon monoxide at ambient temperatures and 77 K. (A temperature of 15 °C was assumed for the conversion of the values of E/p given in [200] to values of E/N.)

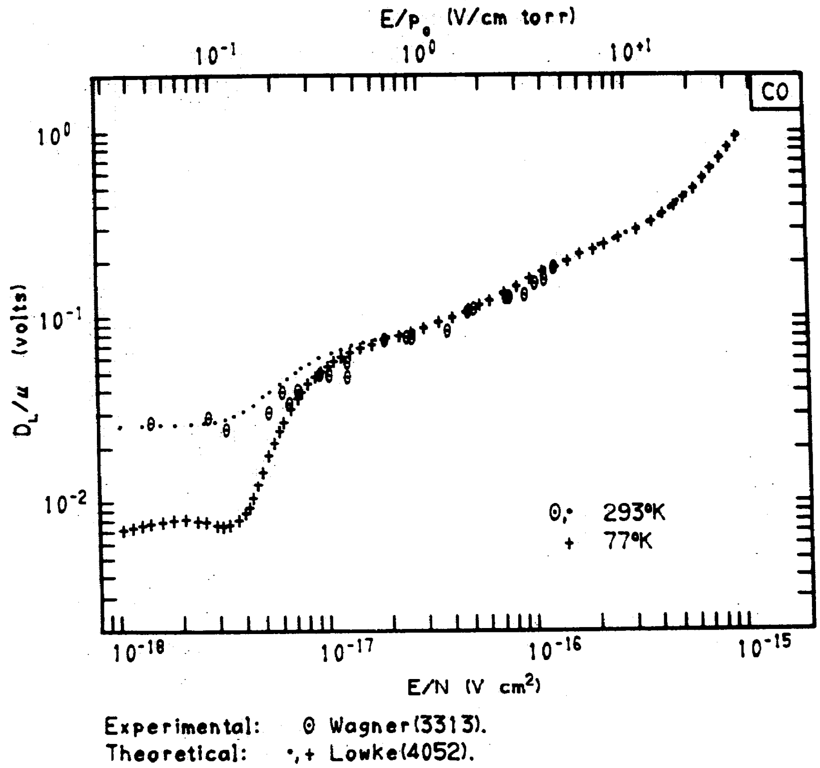


FIGURE 2.19. D_L/μ, E/N for carbon monoxide at 293 K and 77 K.

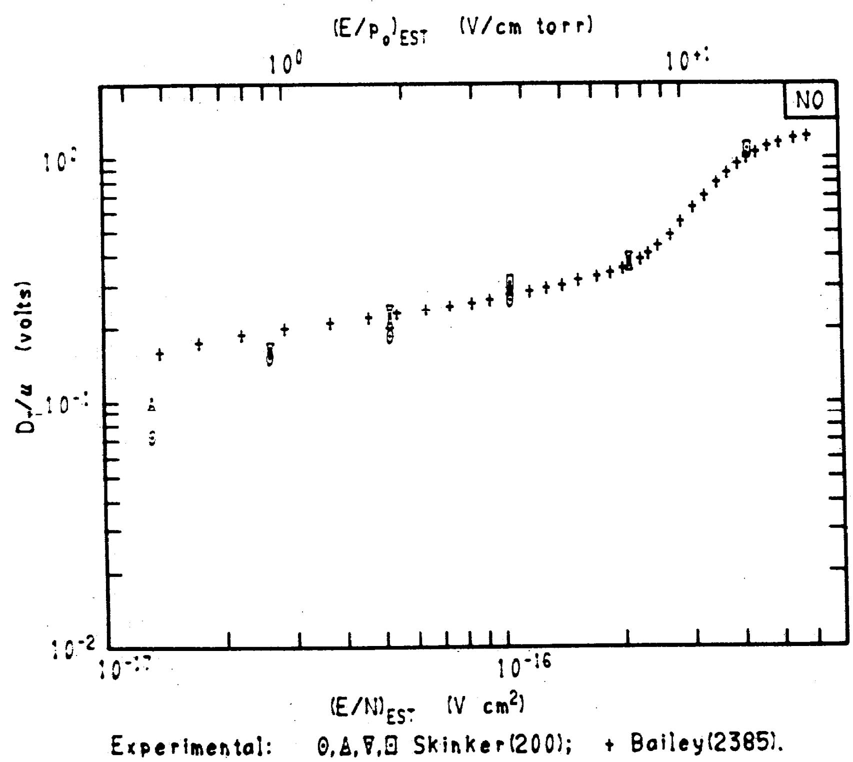


FIGURE 2.20. Experimental D_T/μ, $(E/N)_{Est}$ for nitric oxide. (A temperature of 15 °C was assumed in both cases to convert the given values of E/p to values of E/N.)

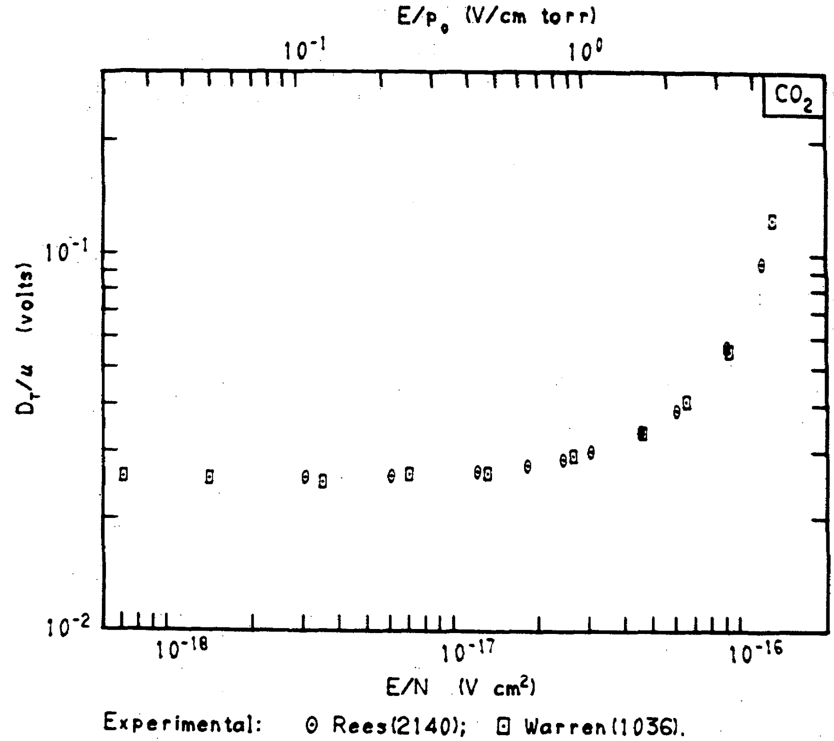


FIGURE 2.21. Experimental D_T/μ, E/N for carbon dioxide for $E/N < 14 \times 10^{-17}$ V cm^2.

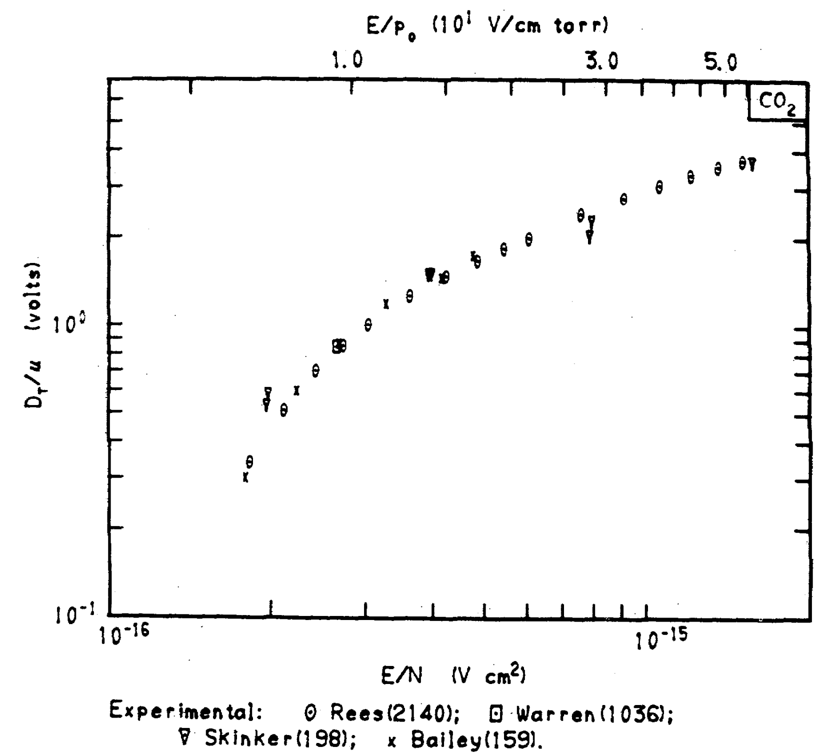


FIGURE 2.22. Experimental D_T/μ, E/N for carbon dioxide for $E/N > 14 \times 10^{-17}$ V cm^2.

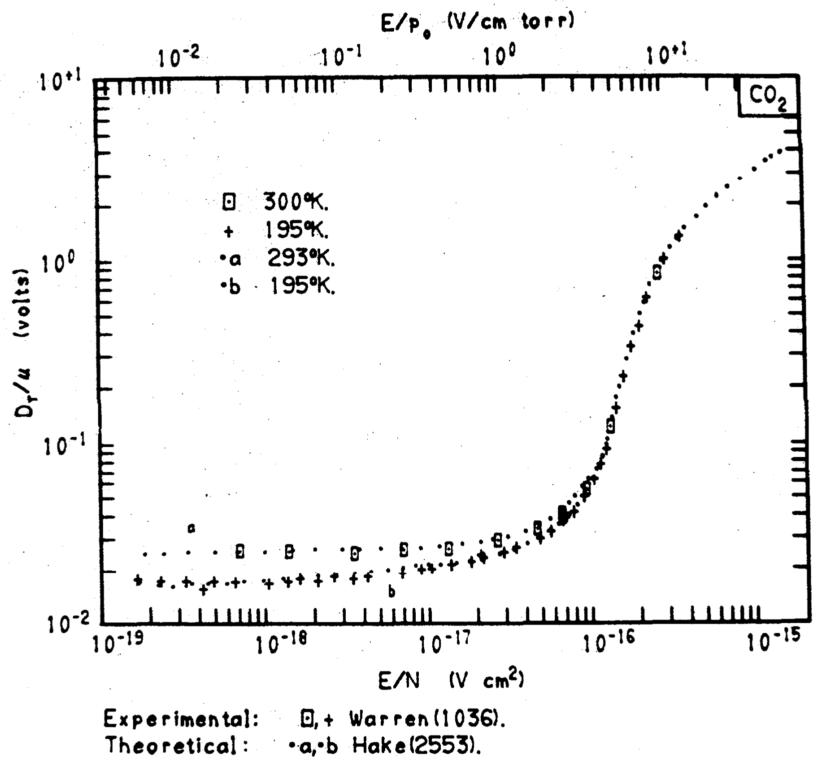


FIGURE 2.23. D_T/μ, E/N for carbon dioxide at various temperatures.

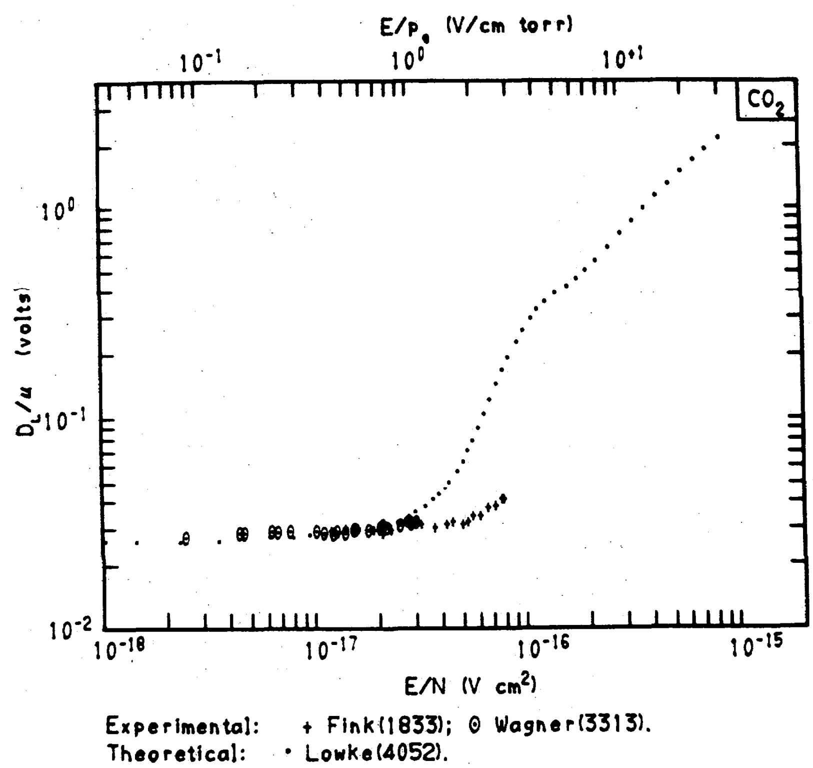


FIGURE 2.24. D_L/μ, E/N for carbon dioxide for $E/N < 10^{-15}$ V cm^2.

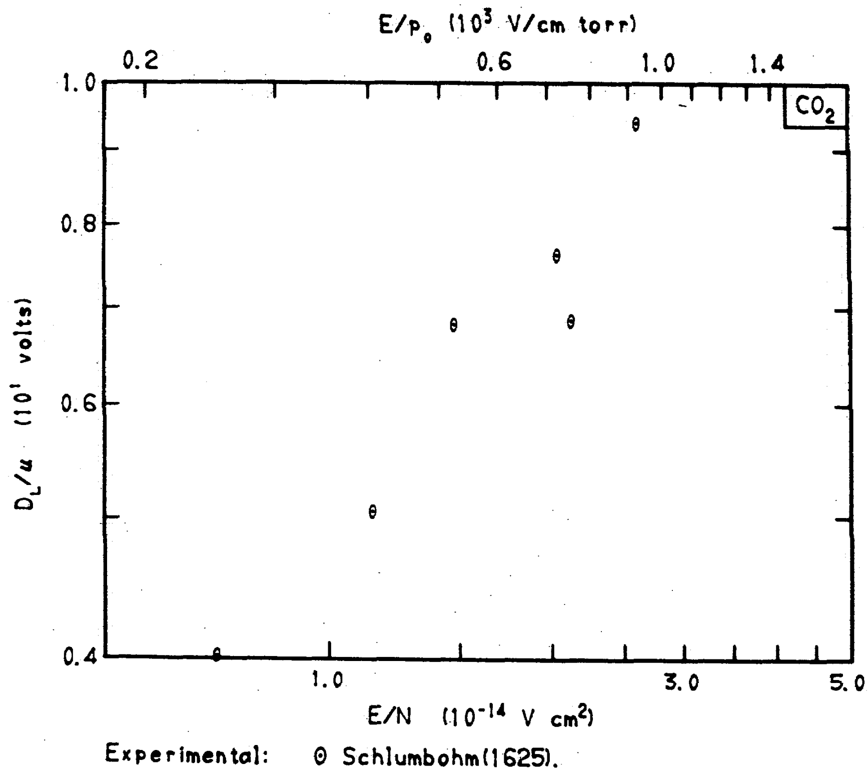


FIGURE 2.25. Experimental D_L/μ, E/N for carbon dioxide for $E/N > 10^{-15}$ V cm².

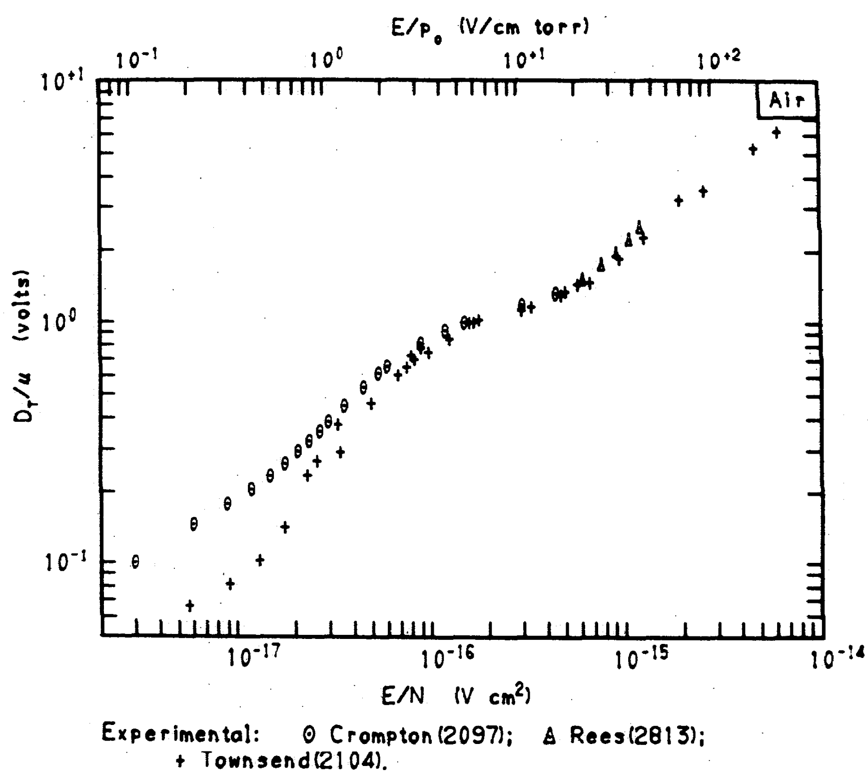


FIGURE 2.26. Experimental D_T/μ, E/N for dry air. (The data of [2097] and [2813] refer to dry air with CO_2 removed, whereas the data of [2104] refer to dry air containing CO_2. The temperature assumed for the conversion of E/p to E/N in [2104] is 15 °C.)

Table 2.1(a)

Values of D_T/μ for helium at ambient temperatures

E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)		E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)		E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)	
0.001133	0.203	(a)	0.02124	0.302	(b)	0.455	2.170	(b)
0.001804	0.234	(a)	0.02430	0.313	(b)	0.546	2.545	(b)
0.002834	0.256	(a)	0.02730	0.325	(b)	0.607	2.789	(b)
0.00360	0.255	(a)	0.0303	0.337	(b)	0.759	3.400	(b)
0.00515	0.254	(a)	0.0364	0.362	(b)	0.910	3.990	(b)
0.00543	0.254	(a)	0.0455	0.400	(b)	1.214	5.20	(b)
0.00720	0.260	(a)	0.0546	0.441	(b)	1.517	6.40	(b)
0.00776	0.260	(a)	0.0607	0.468	(b)	1.820	7.55	(b)
0.00823	0.262	(a)	0.0759	0.534	(b)	2.124	8.76	(b)
0.01133	0.271	(a)	0.0910	0.604	(b)	2.43	9.96	(b)
0.01177	0.266	(a)	0.1214	0.741	(b)	2.730	11.17	(b)
0.01242	0.275	(a)	0.1517	0.874	(b)	3.03	12.41	(b)
0.01645	0.279	(a)	0.1820	1.01	(b)	5.02	22.8	(c)
0.01707	0.284	(a)	0.2124	1.141	(b)	8.35	33.	(c)
0.01773	0.280	(a)	0.243	1.271	(b)	10.07	36.	(c)
0.01804	0.295	(a)	0.273	1.405	(b)	12.52	39.	(c)
0.01878	0.295	(a)	0.303	1.536	(b)	15.80	44.	(c)
			0.364	1.792	(b)			

Experimental:

(a) Warren, et al., Phys. Rev. 128, 2661 (1962), data taken at 300 K.
(b) Crompton, et al., Austr. J. Phys. 20, 369 (1967), data taken at 293 K.
(c) Townsend, et al., Phil. Mag. 46, 657 (1923), data taken at 288 K.

Table 2.1(b)

Values of D_T/μ for helium at 77 K

E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1}V)	E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1}V)	E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1}V)
0.0002943	0.066	0.00882	0.094	0.0615	0.34
0.000463	0.065	0.00959	0.096	0.0751	0.41
0.000537	0.063	0.00990	0.098	0.0779	0.40
0.000736	0.067	0.01158	0.113	0.0820	0.45
0.000820	0.064	0.01161	0.093	0.0829	0.44
0.000844	0.063	0.01183	0.104	0.0844	0.48
0.001158	0.069	0.01236	0.115	0.0882	0.47
0.001236	0.066	0.01288	0.112	0.0959	0.49
0.001288	0.065	0.01344	0.116	0.0990	0.52
0.001344	0.065	0.01416	0.116	0.1161	0.58
0.001475	0.067	0.01475	0.129	0.1183	0.61
0.001940	0.066	0.01506	0.118	0.1236	0.635
0.001984	0.066	0.01524	0.120	0.1288	0.67
0.002052	0.066	0.01822	0.133	0.1344	0.73
0.002105	0.070	0.01984	0.144	0.1416	0.71
0.002114	0.069	0.02052	0.150	0.1506	0.77
0.002689	0.069	0.02114	0.156	0.1524	0.75
0.002943	0.071	0.02151	0.150	0.1822	0.88
0.00301	0.070	0.02397	0.160	0.1940	0.95
0.00309	0.068	0.02689	0.185	0.1984	0.96
0.00311	0.070	0.02903	0.187	0.2052	1.02
0.00323	0.071	0.0301	0.194	0.2151	1.05
0.00385	0.074	0.0305	0.190	0.2397	1.11
0.00410	0.074	0.0309	0.203	0.2903	1.35
0.00463	0.077	0.0311	0.199	0.301	1.42
0.00475	0.077	0.0323	0.206	0.305	1.38
0.00484	0.077	0.0385	0.248	0.309	1.44
0.00497	0.074	0.0410	0.250	0.311	1.45
0.00537	0.080	0.0435	0.254	0.456	2.03
0.00587	0.080	0.0456	0.270	0.472	2.12
0.00608	0.094	0.0475	0.279	0.497	2.19
0.00615	0.081	0.0484	0.286	0.581	2.5
0.00736	0.090	0.0497	0.286	0.609	2.6
0.00751	0.084	0.0537	0.32	0.668	2.9
0.00779	0.088	0.0581	0.33	0.829	3.4
0.00820	0.089	0.0587	0.33	0.916	3.8
0.00844	0.092	0.0608	0.33	1.161	5.2

Experimental:
All data taken from Warren, et al., Phys. Rev. 128, 2661 (1962).

Table 2.2

Values of D_L/μ for helium at ambient temperatures

E/N (10^{-17}Vcm^2)	D_L/μ (10^{-1}V)		E/N (10^{-17}Vcm^2)	D_L/μ (10^{-1}V)		E/N (10^{-17}Vcm^2)	D_L/μ (10^{-1}V)	
0.00914	0.253	(a)	0.1563	0.51	(a)	1.184	2.69	(b)
0.01826	0.265	(a)	0.2607	0.83	(a)	1.234	2.83	(b)
0.02442	0.291	(a)	0.2819	0.78	(b)	1.540	3.6	(b)
0.0302	0.293	(a)	0.300	0.89	(a)	1.816	4.2	(b)
0.0441	0.31	(a)	0.397	1.13	(b)	2.031	4.9	(b)
0.0446	0.29	(a)	0.526	1.61	(a)	2.322	5.5	(b)
0.0585	0.34	(a)	0.530	1.45	(b)	2.667	6.4	(b)
0.0736	0.29	(a)	0.728	1.76	(b)	3.00	7.6	(b)
0.1442	0.51	(a)	0.740	1.95	(a)			
0.1457	0.58	(a)	0.915	2.17	(b)			

Experimental:
(a) Crompton, as given in Lowke, et al., Phys. Rev. 181, 302 (1969).
(b) Wagner, et al., J. Chem. Phys. 47, 3138 (1967).

Table 2.3(a)

Values of D_T/μ for argon at 288 K

E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)	E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)	E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)
0.313	23.6	1.252	42.	12.67	77.
0.334	23.8	2.518	68.	17.58	76.
0.501	27.5	3.73	80.	26.11	80.
0.626	31.	6.32	84.	36.1	81.
0.668	32.	8.43	79.	59.0	80.

Experimental:
All data taken from Townsend, et al., Phil. Mag. 44, 1033 (1922).

Table 2.3(b)

Values of D_T/μ for argon at 77 K

E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)	E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)	E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)
0.000466	0.066	0.001257	0.080	0.002524	0.182
0.000553	0.0663	0.001630	0.085	0.002794	0.277
0.000699	0.069	0.001760	0.093	0.00302	0.39
0.000931	0.072	0.002012	0.106	0.0627	13.6
0.001006	0.075	0.002328	0.144	0.0931	15.1
				0.1257	16.4

Experimental:
All data taken from Warren, et al., Phys. Rev. 128, 2661 (1962).

Table 2.3(c)

Values of D_T/μ for argon at 88 K

E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)	E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)	E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)
0.00311	0.65	0.00584	2.91	0.02561	8.8
0.00348	1.03	0.00730	3.5	0.02924	8.8
0.00394	1.50	0.01024	4.7	0.0363	10.2
0.00438	1.91	0.01462	6.4	0.0410	10.0
		0.02189	8.0	0.0512	11.5

Experimental:
All data taken from Warren, et al., Phys. Rev. 128, 2661, (1962).

Table 2.4(a)

Values of D_L/μ for argon at ambient temperature

E/N (10^{-17}Vcm^2)	D_L/μ (10^{-1}V)	E/N (10^{-17}Vcm^2)	D_L/μ (10^{-1}V)	E/N (10^{-17}Vcm^2)	D_L/μ (10^{-1}V)
0.0445	1.91	0.607	5.6	1.473	7.4
0.0971	2.38	0.797	6.1	1.866	8.1
0.1659	3.6	0.963	6.4	2.080	8.6
0.2509	3.8	1.101	6.6	2.384	9.0
0.312	4.2	1.271	6.9	2.578	9.2
0.437	4.6	1.384	7.4	3.02	10.4

Experimental:
All data taken from Wagner, et al., J. Chem. Phys. 47, 3138, (1967).

Table 2.4(b)

Values of D_L/μ for argon at 77 K

E/N (10^{-17} Vcm^2)	D_L/μ (10^{-1}V)	E/N (10^{-17} Vcm^2)	D_L/μ (10^{-1}V)	E/N (10^{-17} Vcm^2)	D_L/μ (10^{-1}V)
0.000300	0.068 (2)	0.00364	2.49 (1)	0.00991	0.84 (2)
0.000303	0.067 (1)	0.00378	1.23 (2)	0.01214	0.84 (1)
0.000455	0.067 (1)	0.00394	2.58 (1)	0.01242	0.86 (2)
0.000552	0.070 (2)	0.00406	1.55 (2)	0.01721	0.91 (2)
0.000607	0.068 (1)	0.00418	1.81 (2)	0.0182	0.93 (1)
0.001043	0.073 (2)	0.00425	2.43 (1)	0.02349	1.02 (2)
0.001214	0.076 (1)	0.00436	1.86 (2)	0.0243	1.03 (1)
0.001551	0.082 (2)	0.00455	2.11 (1)	0.0303	1.12 (1)
0.00182	0.120 (1)	0.00461	1.98 (2)	0.0420	1.32 (2)
0.002001	0.103 (2)	0.00495	1.89 (2)	0.0455	1.33 (1)
0.002209	0.119 (2)	0.00539	1.71 (2)	0.0607	1.53 (1)
0.002371	0.148 (2)	0.00546	1.41 (1)	0.0876	1.80 (2)
0.00243	0.455 (1)	0.00570	1.51 (2)	0.1909	2.59 (2)
0.002545	0.192 (2)	0.00607	1.09 (1)	0.4790	3.9 (2)
0.002732	0.268 (2)	0.00612	1.30 (2)	1.073	5.7 (2)
0.002974	0.40 (2)	0.00676	1.11 (2)	1.864	7.2 (2)
0.00303	1.49 (1)	0.00715	0.97 (2)	3.15	9.4 (2)
0.00306	0.53 (2)	0.00801	0.91 (2)		
0.00324	0.68 (2)	0.00872	0.87 (2)		
0.00348	0.94 (2)	0.00910	0.82 (1)		

Theoretical:

(1) Lowke, et al., Phys. Rev. 181, 302 (1969), using q_m given in Engelhardt, et al., Phys. Rev. 133, A375 (1964).

(2) Ibid., using values of q_m given by Golden, Phys. Rev. 151, 48 (1966).

Table 2.5(a)

Values of D_T/μ for krypton

E/N (10^{-17} Vcm^2)	D_T/μ (V)	E/N (10^{-17} Vcm^2)	D_T/μ (V)	E/N (10^{-17} Vcm^2)	D_T/μ (V)
0.002083	0.0261	0.01715	0.229	0.0417	0.85
0.00400	0.0268	0.019	0.292	0.0659	1.26
0.00659	0.0291	0.02083	0.35	0.2083	2.78
0.00932	0.039	0.02553	0.49	0.659	5.2
0.01318	0.106	0.02946	0.59	2.083	8.3

Theoretical:

All data taken from Frost, et al., Phys. Rev. 136, A1538 (1964).

Table 2.5(b)

Values of D_L/μ for krypton

E/N (10^{-17}Vcm^2)	D_L/μ (V)	E/N (10^{-17}Vcm^2)	D_L/μ (V)	E/N (10^{-17}Vcm^2)	D_L/μ (V)
0.002083	0.0263	0.01715	0.515	0.0417	0.221
0.00400	0.0279	0.019	0.538	0.0659	0.214
0.00659	0.0337	0.02083	0.512	0.2083	0.293
0.00932	0.0673	0.02553	0.381	0.659	0.467
0.01318	0.281	0.02946	0.299	2.083	0.821

Theoretical:
All data taken from Lowke, et al., Phys. Rev. 181, 302 (1969).

Table 2.6(a)

Values of D_T/μ for xenon

E/N (10^{-17}Vcm^2)	D_T/μ (V)	E/N (10^{-17}Vcm^2)	D_T/μ (V)	E/N (10^{-17}Vcm^2)	D_T/μ (V)
0.002494	0.0259	0.0400	0.210	0.1576	1.21
0.0100	0.0268	0.0499	0.35	0.2494	1.65
0.01576	0.0289	0.066	0.55	0.788	3.2
0.02494	0.052	0.0788	0.67	2.494	5.4
0.0353	0.146	0.1114	0.93		

Theoretical:
All data taken from Frost, et al., Phys. Rev. 136, A1538 (1964).

Table 2.6(b)

Values of D_L/μ for xenon

E/N (10^{-17}Vcm^2)	D_L/μ (V)	E/N (10^{-17}Vcm^2)	D_L/μ (V)	E/N (10^{-17}Vcm^2)	D_L/μ (V)
0.002494	0.0260	0.0400	0.44	0.1576	0.208
0.0100	0.0281	0.0499	0.47	0.2494	0.233
0.01576	0.034	0.066	0.32	0.788	0.33
0.02494	0.108	0.0788	0.243	2.494	0.61
0.0353	0.34	0.1114	0.194		

Theoretical:
All data taken from Lowke, et al., Phys. Rev. 181, 302 (1969).

Table 2.7

Values of D_T/μ for hydrogen at ambient temperatures

E/N (10^{-17} Vcm^2)	D_T/μ (V)		E/N (10^{-17} Vcm^2)	D_T/μ (V)		E/N (10^{-17} Vcm^2)	D_T/μ (V)	
0.01821	0.0258	(a)	3.64	0.267	(a)	134.7	3.2	(c)
0.02428	0.0262	(a)	4.55	0.310	(a)	138.5	3.2	(b)
0.0304	0.0265	(a)	5.46	0.350	(a)	142.6	3.5	(d)
0.0455	0.0275	(a)	6.07	0.374	(a)	153.6	3.3	(b)
0.0607	0.0286	(a)	13.24	0.60	(d)	157.2	3.7	(d)
0.0759	0.0297	(a)	18.24	0.84	(c)	162.8	3.5	(c)
0.0911	0.0308	(a)	26.66	1.16	(c)	169.5	3.5	(b)
0.1214	0.0330	(a)	28.20	1.02	(d)	171.5	3.8	(d)
0.1518	0.0353	(a)	31.0	1.08	(b)	184.5	3.6	(b)
0.1821	0.0375	(a)	39.3	1.54	(c)	188.0	3.7	(c)
0.2125	0.0396	(a)	41.4	1.47	(d)	200.0	3.8	(b)
0.2428	0.0418	(a)	45.6	1.56	(b)	215.9	4.0	(b)
0.2732	0.0439	(a)	53.3	1.92	(c)	216.1	4.0	(c)
0.304	0.0459	(a)	56.4	1.95	(d)	254.0	4.2	(c)
0.364	0.0500	(a)	61.9	2.00	(b)	294.6	4.5	(c)
0.455	0.0562	(a)	68.8	2.27	(c)	340	4.7	(c)
0.546	0.0625	(a)	70.3	2.40	(d)	379	4.9	(c)
0.607	0.0668	(a)	77.4	2.32	(b)	425	5.1	(c)
0.759	0.0779	(a)	84.9	2.65	(d)	469	5.3	(c)
0.911	0.0888	(a)	87.0	2.62	(c)	521	5.5	(c)
1.214	0.1112	(a)	92.5	2.55	(b)	580	5.7	(c)
1.518	0.1334	(a)	98.8	2.84	(d)	651	6.0	(c)
1.821	0.1551	(a)	107.9	2.78	(b)	721	6.2	(c)
2.125	0.1761	(a)	110.8	2.98	(c)	798	6.5	(c)
2.428	0.1962	(a)	113.4	3.2	(d)	884	6.7	(c)
2.732	0.215	(a)	123.4	2.97	(b)	995	7.1	(c)
3.04	0.233	(a)	127.3	3.2	(d)			

Experimental:
(a) Crompton, et al., Austr. J. Phys. 21, 43 (1968).
(b) Crompton, et al., in Proc. of the Seventh International Conf. Phen. Ion. Gases (Belgrade, 22-27 August 1965) B. Perovic and D. Tosic, eds., Gradevinska Knjiga Publishing House, Belgrade 1, 86 (1966).
(c) Lawson, et al., Brit. J. Appl. Phys. 16, 1813 (1965).
(d) Virr, et al., 1st Int. Conf. Gas Discharges, London 530 (1970).

Table 2.8

Values of D_L/μ for hydrogen at ambient temperature

E/N (10^{-17} Vcm^2)	D_L/μ (10^{-1} V)	E/N (10^{-17} Vcm^2)	D_L/μ (10^{-1} V)	E/N (10^{-17} Vcm^2)	D_L/μ (10^{-1} V)
0.1394	0.275	0.737	0.41	2.143	0.83
0.1879	0.286	0.858	0.46	2.455	0.93
0.2698	0.30	0.982	0.47	2.561	0.99
0.336	0.33	1.112	0.53	3.05	1.12
0.400	0.34	1.155	0.56	3.64	1.28
0.524	0.37	1.358	0.63	4.56	1.60
0.582	0.40	1.464	0.65	5.02	1.67
0.646	0.39	1.955	0.77	5.86	1.87

Experimental:
All data taken from Wagner, et al., J. Chem. Phys. 47, 3138 (1967).

Table 2.9

Values of D_T/μ for hydrogen at 77 K

E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)		E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)		E/N (10^{-17}Vcm^2)	D_T/μ (10^{-1}V)	
0.000484	0.066	(a)	0.0300	0.118	(b)	1.600	1.31	(b)
0.000491	0.066	(a)	0.0350	0.127	(b)	1.800	1.45	(b)
0.000761	0.066	(a)	0.0400	0.135	(b)	2.000	1.60	(b)
0.000770	0.064	(a)	0.0450	0.143	(b)	2.50	1.93	(b)
0.000969	0.068	(a)	0.0500	0.151	(b)	3.00	2.24	(b)
0.001232	0.069	(a)	0.0600	0.165	(b)	3.50	2.52	(b)
0.001326	0.061	(a)	0.0700	0.178	(b)	4.00	2.78	(b)
0.001385	0.070	(a)	0.0800	0.189	(b)	4.50	3.02	(b)
0.001919	0.067	(a)	0.0900	0.200	(b)	5.00	3.25	(b)
0.001937	0.068	(a)	0.1000	0.210	(b)	6.00	3.66	(b)
0.002000	0.0676	(b)	0.1200	0.229	(b)	7.00	4.05	(b)
0.002500	0.0681	(b)	0.1400	0.247	(b)	8.00	4.40	(b)
0.00300	0.0685	(b)	0.1600	0.263	(b)	9.00	4.74	(b)
0.00350	0.0690	(b)	0.1800	0.278	(b)	10.00	5.06	(b)
0.00400	0.0696	(b)	0.2000	0.294	(b)	12.00	5.65	(b)
0.00450	0.0702	(b)	0.2500	0.329	(b)	14	6.11	(1)
0.00500	0.0709	(b)	0.300	0.364	(b)	17	6.94	(1)
0.00600	0.0723	(b)	0.350	0.398	(b)	20	7.24	(1)
0.00700	0.0738	(b)	0.400	0.433	(b)	30	10.71	(1)
0.00800	0.0755	(b)	0.450	0.467	(b)	40	14.73	(1)
0.00900	0.0772	(b)	0.500	0.502	(b)	50	18.68	(1)
0.01000	0.0790	(b)	0.600	0.572	(b)	60	22.9	(1)
0.01200	0.0827	(b)	0.700	0.642	(b)	70	26.3	(1)
0.01400	0.0867	(b)	0.800	0.713	(b)	80	29.6	(1)
0.01600	0.0907	(b)	0.900	0.786	(b)	90	32.4	(1)
0.01800	0.0946	(b)	1.000	0.860	(b)	100	35.0	(1)
0.02000	0.0986	(b)	1.200	1.01	(b)	125	39.9	(1)
0.02500	0.108	(b)	1.400	1.16	(b)	150	44.5	(1)

Experimental:
(a) Warren, et al., Phys. Rev. 128, 2661 (1962).
(b) Crompton, et al., Austr. J. Phys. 21, 43 (1968).
Theoretical:
(1) Engelhardt, et al., Phys. Rev. 131, 2115 (1963).

Table 2.10

Values of D_T/μ for nitrogen at ambient temperatures

E/N (10^{-17} Vcm^2)	D_T/μ (V)		E/N (10^{-17} Vcm^2)	D_T/μ (V)		E/N (10^{-17} Vcm^2)	D_T/μ (V)	
0.01833	0.0262	(a)	0.620	0.180	(a)	9.17	0.88	(a)
0.02451	0.0270	(a)	0.758	0.219	(b)	12.12	0.98	(b)
0.0310	0.0279	(a)	0.909	0.256	(b)	12.26	0.94	(a)
0.0469	0.0305	(a)	0.937	0.255	(a)	14.90	1.07	(c)
0.0620	0.033	(a)	1.212	0.33	(b)	15.16	1.04	(b)
0.0775	0.037	(a)	1.516	0.39	(b)	18.19	1.09	(b)
0.0927	0.040	(a)	1.567	0.38	(a)	20.13	1.11	(d)
0.1212	0.048	(b)	1.819	0.45	(b)	21.22	{1.12	(b)
0.1240	0.048	(a)	1.874	0.44	(a)		1.13	(e)
0.1516	0.057	(b)	2.122	0.50	(b)	24.25	1.15	(b)
0.1567	0.057	(a)	2.192	0.48	(a)	29.80	1.25	(c)
0.1819	0.066	(b)	2.425	0.54	(b)	30.3	1.25	(e)
0.1874	0.066	(a)	2.479	0.51	(a)	40.4	1.29	(d)
0.2122	0.075	(b)	2.728	0.57	(b)	44.7	1.36	(c)
0.2192	0.075	(a)	2.77	0.55	(a)	45.5	1.36	(e)
0.2425	0.085	(b)	3.03	0.61	(b)	59.6	1.48	(c)
0.2479	0.083	(a)	3.13	0.58	(a)	60.6	1.46	(e)
0.2728	0.094	(b)	3.64	0.66	(b)	74.5	1.63	(c)
0.2803	0.093	(a)	4.53	0.69	(a)	75.8	1.59	(e)
0.303	0.103	(b)	4.55	0.72	(b)	80.5	1.68	(d)
0.364	0.120	(b)	5.46	0.77	(b)	90.9	1.76	(e)
0.455	0.145	(b)	6.06	0.80	(b)	106.1	1.97	(e)
0.464	0.142	(a)	6.13	0.77	(a)	121.2	2.19	(e)
0.546	0.168	(b)	7.58	0.85	(b)	163.8	2.95	(d)
0.606	0.182	(b)	9.09	0.90	(b)			

Experimental:

(a) Crompton, et al., in Proceedings of the Sixth International Conference on Ionization Phenomena in Gases, Paris 8-13 July 1963, (P. Hubert and E. Cremieu-Alcan, Eds., Serma, Paris, 1963), Vol. 1, p. 337.

(b) Jory, Austr. J. Phys. 18, 237 (1965).

(c) Crompton, et al., Proc. Roy. Soc. London, Ser A 215, 467 (1952).

(d) Townsend, et al., Phil. Mag. 42, 874 (1921).

(e) Naidu, et al., Brit. J. Appl. Phys. (J. Phys. D 2) 1, 763 (1968).

Table 2.11

Values of D_T/μ for nitrogen at 77 K

E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1} V)		E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1} V)		E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1} V)	
0.000699	0.067	(a)	0.0320	0.104	(a)	1.009	2.87	(a)
0.000813	0.065	(a)	0.0385	0.115	(a)	1.267	3.3	(a)
0.000832	0.066	(a)	0.0506	0.136	(a)	1.279	3.4	(a)
0.001397	0.067	(a)	0.0574	0.155	(a)	1.599	4.1	(a)
0.002033	0.068	(a)	0.0633	0.165	(a)	2.018	5.0	(a)
0.002080	0.068	(a)	0.0640	0.168	(a)	2.238	5.2	(a)
0.002555	0.065	(a)	0.0770	0.202	(a)	2.530	5.4	(a)
0.002794	0.070	(a)	0.0894	0.230	(a)	5.06	7.6	(a)
0.00376	0.069	(a)	0.1009	0.30	(a)	8.41	8.8	(a)
0.00407	0.068	(a)	0.1267	0.34	(a)	10	9.9	(1)
0.00640	0.068	(a)	0.1276	0.34	(a)	20	1.16	(1)
0.00699	0.074	(a)	0.1605	0.45	(a)	30	1.26	(1)
0.00751	0.072	(a)	0.1925	0.57	(a)	40	1.34	(1)
0.00770	0.068	(a)	0.2018	0.57	(a)	50	1.42	(1)
0.00813	0.073	(a)	0.2530	0.79	(a)	60	1.51	(1)
0.01087	0.076	(a)	0.2555	0.78	(a)	70	1.60	(1)
0.01276	0.074	(a)	0.320	0.99	(a)	110	2.10	(1)
0.01599	0.078	(a)	0.385	1.21	(a)	140	2.53	(1)
0.01925	0.083	(a)	0.506	1.50	(a)	180	3.1	(1)
0.02033	0.095	(a)	0.633	1.89	(a)	240	3.9	(1)
0.02530	0.091	(a)	0.770	2.22	(a)	300	4.7	(1)
0.02555	0.093	(a)	0.863	2.43	(a)	400	5.9	(1)

Experimental:
(a) Warren, et al., Phys. Rev. 128, 2661 (1962).
Theoretical:
(1) Engelhardt, et al., Phys. Rev. 135, A1566 (1964).

Table 2.12

Values of D_L/μ for nitrogen at ambient temperatures

E/N (10^{-17} Vcm^2)	D_L/μ (V)		E/N (10^{-17} Vcm^2)	D_L/μ (V)		E/N (10^{-17} Vcm^2)	D_L/μ (V)	
0.0104	.026	(1)	1.164	0.146	(a)	200	2.47	(1)
0.0136	.026	(1)	1.476	0.178	(a)	334	4.5	(b)
0.0171	.026	(1)	1.664	0.207	(a)	469	5.1	(b)
0.0240	.026	(1)	2.209	0.266	(a)	491	7.2	(b)
0.0304	.025	(1)	2.761	0.31	(a)	616	6.3	(b)
0.0402	.025	(1)	3.21	0.31	(a)	729	5.3	(b)
0.0526	.026	(1)	3.85	0.37	(a)	977	5.7	(b)
0.0671	.026	(1)	4.56	0.39	(a)	1064	7.9	(b)
0.0828	.027	(1)	5.37	0.43	(a)	1310	7.0	(b)
0.105	.028	(1)	6.05	0.44	(a)	1592	10.1	(b)
0.128	.029	(1)	10.0	0.42	(1)	1898	9.6	(b)
0.1455	.027	(a)	20.0	0.45	(1)	2749	11.8	(b)
0.2606	.038	(a)	40.0	0.50	(1)	3660	19.1	(b)
0.561	.075	(a)	60.0	0.63	(1)	5440	29.6	(b)
0.867	.115	(a)	100	1.22	(1)	8470	37	(b)

Experimental:
(a) Wagner, et al., J. Chem. Phys. 47, 3138 (1967).
(b) Schlumbohm, Z. Physik 184, 492 (1965).
Theoretical:
(1) Lowke, et al., Phys. Rev. 181, 302 (1969).

Table 2.13

Values of D_T/μ for oxygen

E/N (10^{-17} Vcm^2)	D_T/μ (V)		E/N (10^{-17} Vcm^2)	D_T/μ (V)		E/N (10^{-17} Vcm^2)	D_T/μ (V)	
0.01029	0.0241	(1)	0.457	0.108	(1)	9.0	1.01	(a)
0.01271	0.0241	(1)	0.512	0.115	(1)	9.07	0.99	(a)
0.01403	0.0241	(1)	0.565	0.121	(1)	9.09	0.98	(b)
0.01662	0.0244	(1)	0.615	0.126	(1)	10.0	1.08	(a)
0.01886	0.0244	(1)	0.669	0.131	(1)	12.0	1.27	(a)
0.02234	0.0248	(1)	0.749	0.137	(1)	12.12	1.31	(b)
0.02537	0.0249	(1)	0.850	0.145	(1)	12.22	1.29	(a)
0.02963	0.0251	(1)	0.993	0.159	(1)	14.0	1.47	(a)
0.0341	0.0257	(1)	1.0	0.14	(a)	14.90	1.57	(c)
0.0398	0.0260	(1)	1.189	0.185	(a)	15.0	1.55	(a)
0.0465	0.0266	(1)	1.212	0.188	(b)	15.16	1.60	(b)
0.0551	0.0276	(1)	1.489	0.205	(a)	15.20	1.57	(a)
0.0653	0.0288	(1)	1.516	0.207	(b)	15.40	1.57	(d)
0.0741	0.0296	(1)	1.785	0.225	(a)	16.0	1.73	(a)
0.0865	0.031	(1)	1.819	0.225	(b)	17.88	1.81	(c)
0.0969	0.033	(1)	2.0	0.21	(a)	18.19	1.84	(b)
0.1116	0.035	(1)	2.382	0.256	(a)	18.32	1.84	(a)
0.1284	0.039	(1)	2.425	0.258	(b)	22.35	2.05	(c)
0.1418	0.042	(1)	2.980	0.293	(a)	29.80	2.32	(c)
0.1587	0.046	(1)	3.0	0.31	(a)	30.0	2.23	(d)
0.1777	0.050	(1)	3.03	0.293	(b)	37.3	2.51	(c)
0.1961	0.054	(1)	4.0	0.40	(a)	44.7	2.68	(c)
0.2134	0.057	(1)	4.54	0.43	(a)	45.0	2.58	(d)
0.2323	0.063	(1)	4.55	0.43	(b)	52.2	2.80	(c)
0.2528	0.068	(1)	5.0	0.53	(a)	59.6	2.93	(c)
0.2751	0.073	(1)	5.99	0.60	(a)	60.1	2.87	(d)
0.308	0.080	(1)	6.0	0.65	(a)	75.2	3.1	(d)
0.335	0.087	(1)	6.06	0.60	(b)	90.2	3.3	(d)
0.365	0.092	(1)	7.0	0.76	(a)	105.9	3.5	(d)
0.403	0.099	(1)	8.0	0.89	(a)	121.2	3.6	(d)
						136.9	3.8	(d)
						150.7	4.0	(d)

Experimental:
(a) Fleming, et al., J. Phys. D 5, 291 (1972).
(b) Rees, Austr. J. Phys. 18, 41 (1965).
(c) Huxley, et al., Austr. J. Phys. 12, 303 (1959).
(d) Naidu, et al., J. Phys. D 3, 957 (1970).
Theoretical:
(1) Hake, et al., Phys. Rev. 158, 70 (1967).

Table 2.14

Values of D_L/μ for oxygen

E/N (10^{-17} Vcm^2)	D_L/μ (V)		E/N (10^{-17} Vcm^2)	D_L/μ (V)		E/N (10^{-17} Vcm^2)	D_L/μ (V)	
0.0543	0.0279	(a)	1.232	0.086	(a)	20.0	1.36	(1)
0.0697	0.0296	(a)	1.386	0.084	(a)	40.0	1.80	(1)
0.0851	0.033	(a)	1.540	0.090	(a)	80.0	2.22	(1)
0.1128	0.0297	(a)		0.085	(a)	150	2.69	(1)
0.1313	0.031	(a)	1.694	0.096	(a)	211	4.9	(b)
0.1467	0.030	(a)	1.848	0.101	(a)	267	5.0	(b)
0.1621	0.037	(a)	2.002	0.101	(a)	333	4.8	(b)
0.1775	0.034	(a)	2.156	0.106	(a)	446	6.5	(b)
0.2237	0.045	(a)		0.100	(a)	452	5.5	(b)
0.2853	0.042	(a)	2.310	0.104	(a)	457	4.5	(b)
0.347	0.062	(a)	2.464	0.109	(a)	685	7.8	(b)
0.493	0.058	(a)	2.618	0.108	(a)		5.9	(b)
0.616	0.066	(a)	2.772	0.115	(a)	1165	7.4	(b)
	0.065	(a)		0.113	(a)	1192	9.4	(b)
0.770	0.071	(a)	2.926	0.118	(a)	1994	12.4	(b)
	0.069	(a)						
			3.080	0.123	(a)	2017	14.8	(b)
0.924	0.074	(a)	3.5	0.193	(1)	2804	15.6	(b)
	0.075	(a)	5.00	0.285	(1)	3130	14.5	(b)
	0.073	(a)	7.00	0.47	(1)	6870	25.6	(b)
1.078	0.079	(a)	10.0	0.76	(1)	12890	34	(b)
	0.081	(a)						

Experimental:
(a) Nelson, et al., J. Chem. Phys. 57, 4079 (1972).
(b) Schlumbohm, Z. Physik 184, 492 (1965).
Theoretical:
(1) Lowke, et al., Phys. Rev. 181, 302 (1969).

Table 2.15(a)

Values of D_T/μ for carbon monoxide at ambient temperatures

E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1}V)		E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1}V)		E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1}V)	
0.100	0.273	(1)	0.638	0.76	(a)	10.19	4.3	(a)
0.200	0.340	(1)	1.276	1.15	(a)	20.41	7.0	(a)
0.300	0.448	(1)	2.551	1.59	(a)	40.8	9.5	(a)
0.319	0.47	(a)	5.10	2.50	(a)	81.6	12.0	(a)
						163.3	22.8	(a)

Experimental:
(a) Skinker, et al., Phil. Mag. 46, 630 (1923).
Theoretical:
(1) Lowke, et al., Phys. Rev. 181, 302 (1969).

Table 2.15(b)

Values of D_T/μ for carbon monoxide at 77 K

E/N ($10^{-17}Vcm^2$)	D_T/μ ($10^{-1}V$)		E/N ($10^{-17}Vcm^2$)	D_T/μ ($10^{-1}V$)		E/N ($10^{-17}Vcm^2$)	D_T/μ ($10^{-1}V$)	
0.00354	0.070	(a)	0.2080	0.124	(a)	1.416	1.17	(a)
0.00708	0.069	(a)	0.2477	0.149	(a)	1.664	1.28	(a)
0.01099	0.070	(a)	0.2934	0.176	(a)	2.123	1.50	(a)
0.01416	0.069	(a)	0.354	0.250	(a)	2.642	1.61	(a)
0.02198	0.071	(a)	0.416	0.33	(a)	3.14	1.91	(a)
0.02831	0.076	(a)	0.497	0.44	(a)	4.69	2.48	(a)
0.0354	0.074	(a)	0.556	0.54	(a)	6.15	2.96	(a)
0.0441	0.073	(a)	0.624	0.62	(a)	7.30	3.5	(a)
0.0708	0.077	(a)	0.708	0.70	(a)	11.74	4.9	(a)
0.0879	0.083	(a)	0.832	0.83	(a)	17.60	6.4	(a)
0.1248	0.087	(a)	1.062	0.99	(a)	30	8.1	(1)
0.1416	0.093	(a)	1.174	1.05	(a)	70	10.8	(1)
						100	13.9	(1)

Experimental:
(a) Warren, et al., Phys. Rev. 128, 2661 (1962).
Theoretical:
(1) Hake, et al., Phys. Rev. 158, 70 (1967).

Table 2.16(a)

Values of D_L/μ for carbon monoxide at ambient temperature

E/N ($10^{-17}Vcm^2$)	D_L/μ ($10^{-1}V$)	E/N ($10^{-17}Vcm^2$)	D_L/μ ($10^{-1}V$)	E/N ($10^{-17}Vcm^2$)	D_L/μ ($10^{-1}V$)
0.0407	0.251	0.931	0.49	4.79	1.06
0.1413	0.270	1.031	0.49	5.13	1.10
0.2706	0.289	1.261	0.57	7.33	1.27
0.329	0.252	1.262	0.48	7.66	1.28
0.529	0.31	1.907	0.75	9.05	1.31
0.615	0.40	2.439	0.78	10.19	1.52
0.659	0.35	2.568	0.77	11.28	1.59
0.730	0.41	3.82	0.84	12.54	1.85

Experimental:
All data taken from Wagner, et al., J. Chem. Phys. 47, 3138 (1967).

Table 2.16(b)

Values of D_L/μ for carbon monoxide at 77 K

E/N (10^{-17} Vcm^2)	D_L/μ (10^{-1}V)	E/N (10^{-17} Vcm^2)	D_L/μ (10^{-1}V)	E/N (10^{-17} Vcm^2)	D_L/μ (10^{-1}V)
0.100	0.0712	0.400	0.0913	2.5	0.848
0.200	0.0796	0.55	0.215	6.00	1.22
0.25	0.0787	0.700	0.357	10.0	1.73
0.31	0.0741	1.00	0.543	30.0	2.92
0.35	0.0764	1.7	0.732	70.0	6.22
				100	10.2

Theoretical:
All data taken from Lowke, et al., Phys. Rev. 181, 302 (1969).

Table 2.17(a)

Values of D_T/μ for carbon dioxide at ambient temperatures

E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1}V)	E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1}V)	E/N (10^{-17} Vcm^2)	D_T/μ (10^{-1}V)
0.0702	0.255 (a)	6.58	0.41 (a)	22.51	6.2 (a)
0.1403	0.254 (a)	9.09	0.57 (b)	24.25	7.0 (b)
0.303	0.255 (b)	9.25	0.55 (a)	26.39	8.4 (a)
0.351	0.249 (a)	12.12	0.95 (b)	26.82	8.7 (c)
0.606	0.258 (b)	13.19	1.23 (a)	27.28	8.5 (b)
0.702	0.261 (a)	14.37	1.53 (a)	28.87	10.0 (a)
1.212	0.265 (b)	16.21	2.3 (a)	30.3	10.1 (b)
1.319	0.263 (a)	17.88	2.98 (c)	32.8	11.9 (c)
1.819	0.275 (b)	18.01	3.3 (a)	36.0	13.2 (a)
2.425	0.286 (b)	18.19	3.4 (b)	36.4	12.7 (b)
2.639	0.293 (a)	19.64	5.2 (d)	39.3	14.9 (d)
3.03	0.301 (b)	19.79	5.7 (d)	39.9	15.0 (d)
4.55	0.34 (b)	20.24	4.3 (a)	41.7	14.6 (c)
4.63	0.34 (a)	21.22	5.1 (b)	42.4	14.8 (b)
6.06	0.39 (b)	22.35	6.0 (c)	47.7	17.4 (c)
				48.5	16.7 (b)
				54.6	18.4 (b)

Experimental:
(a) Warren, et al., Phys. Rev. 128, 2661 (1962).
(b) Rees, Austr. J. Phys. 17, 462 (1962).
(c) Bailey, et al., Phil. Mag. 14, 1033 (1932).
(d) Skinker, Phil. Mag. 44, 994 (1922).

Table 2.17(b)

Values of D_T/μ for carbon dioxide at 195 K

E/N $(10^{-17} Vcm^2)$	D_T/μ $(10^{-2} V)$	E/N $(10^{-17} Vcm^2)$	D_T/μ $(10^{-2} V)$	E/N $(10^{-17} Vcm^2)$	D_T/μ $(10^{-2} V)$
0.01639	1.74	0.2620	1.82	2.887	2.50
0.02297	1.70	0.342	1.76	3.45	2.65
0.0329	1.70	0.419	1.82	4.84	2.97
0.0419	1.52	0.683	1.90	5.62	3.3
0.0491	1.70	0.888	2.00	6.64	3.7
0.0655	1.68	1.043	2.02	6.89	3.9
0.1043	1.64	1.366	2.13	7.79	4.1
0.1366	1.69	1.801	2.21	9.00	5.0
0.1636	1.75	2.089	2.40	10.34	6.3
0.2089	1.70	2.173	2.33	11.33	7.7
				12.32	9.2
				13.78	13.8

Experimental:
All data taken from Warren et al., Phys. Rev. 128, 2661 (1962).

Table 2.18

Values of D_L/μ for carbon dioxide

E/N $(10^{-17} Vcm^2)$	D_L/μ (V)	E/N $(10^{-17} Vcm^2)$	D_L/μ (V)	E/N $(10^{-17} Vcm^2)$	D_L/μ (V)
0.2476	0.0271 (a)	1.397	0.0285 (a)	3.03	0.032 (a)
0.443	0.0284 (a)	1.534	0.0296 (a)	12.14	0.139 (1)
0.469	0.0284 (a)	1.560	0.0296 (a)	15	0.242 (1)
0.632	0.0291 (a)	1.789	0.0293 (a)	30.3	0.431 (1)
0.673	0.0287 (a)	2.044	0.030 (a)	60.7	0.903 (1)
0.769	0.0291 (a)	2.095	0.031 (a)	182	2.36 (1)
1.024	0.0291 (a)	2.199	0.030 (a)	704	4.0 (b)
1.112	0.0284 (a)	2.554	0.031 (a)	1145	5.1 (b)
1.234	0.0282 (a)	2.794	0.033 (a)	1472	6.8 (b)
1.282	0.0290 (a)	2.853	0.031 (a)	2036	7.6 (b)
				2124	6.9 (b)
				2604	9.4 (b)

Experimental:
(a) Wagner, et al., J. Chem. Phys. 47, 3138 (1967).
(b) Schlumbohm, Z. Physik 184, 492 (1965).
Theoretical:
(1) Lowke, et al., Phys. Rev. 181, 302 (1969).

Table 2.19

Values of D_T/μ for dry air from which the carbon dioxide has been removed

E/N (10^{-17}Vcm^2)	D_T/μ (V)		E/N (10^{-17}Vcm^2)	D_T/μ (V)		E/N (10^{-17}Vcm^2)	D_T/μ (V)	
0.2980	0.099	(a)	2.682	0.35	(a)	14.90	1.00	(a)
0.600	0.146	(a)	2.980	0.39	(a)	29.80	1.18	(a)
0.894	0.179	(a)	3.58	0.45	(a)	44.7	1.32	(a)
1.192	0.206	(a)	4.47	0.54	(a)	59.6	1.48	(a)
1.490	0.233	(a)	5.36	0.61	(a)	60.6	1.50	(b)
1.788	0.261	(a)	5.96	0.66	(a)	75.8	1.73	(b)
2.086	0.293	(a)	8.94	0.82	(a)	90.9	1.97	(b)
2.384	0.32	(a)	11.92	0.93	(a)	106.1	2.24	(b)
						121.2	2.53	(b)

Experimental:
(a) Crompton, et al., Proc. Roy. Soc. London, Ser A, 218, 507 (1953).
(b) Rees, Austr. J. Phys. 17, 307 (1964).

3.3. Diffusion Coefficient

For an electron swarm in thermal equilibrium with a gas, the diffusion is symmetric and can be characterized by a coefficient of diffusion, which is a constant independent of direction and which will be designated here as the thermal equilibrium diffusion coefficient D_{th}. When equilibrium is disturbed by the application of an electric field E, the diffusion becomes asymmetric and, as mentioned in section 3.2, the diffusion coefficient becomes a tensor, having components D_T and D_L, respectively, in directions perpendicular to and along the direction of the electric field. As $E \rightarrow 0$, both D_T and $D_L \rightarrow D_{th}$.

The only values of D_TN and D_LN given in sections 3.3.b and 3.3.c are those measured directly. Other values for D_LN and D_TN can, of course, be obtained by multiplying the values of D_L/μ and D_T/μ given in section 3.2 by values of $\mu N = W/(E/N)$ obtainable from the results given in section 3.1. Values of $D_{th}N$ can be obtained by extrapolating the data given in previous sections to zero field or by using previously determined values of the cross section in eq (7). Since this involves procedures other than purely arithmetical manipulation of the data given previously, theoretical values of D_{th} are included in section 3.3.a for comparison with the experimental values.

All the coefficients of diffusion are inversely proportional to the number density of the gas, so that it is convenient to present the data as values of $D_{th}N$ and as graphs of D_TN as functions of E/N, as is done in the following sections.

3.3.a. Thermal Equilibrium Diffusion Coefficient D_{th}

The only experimental data for D_{th} are those obtained recently by Cavalleri [4049, 4050] and by Nelson and Davis [4048, 5135]. In Cavalleri's so-called sampling diffusion chamber (SDC) method, the decay of the number of electrons in a gas, initially weakly ionized by a burst of X-rays, was measured. In Nelson and Davis' so-called drift-dwell-drift (DDD) method, an electron swarm produced by a pulsed light source was allowed to drift under the influence of an applied field which was then reduced to zero and subsequently reapplied after a measured period of time which could be varied. The distribution of the time of arrival of the electrons at the detector, which was measured, gave a measure of D_{th}. The experimental values obtained are given in the following tables, where the experimental methods are designated by SDC and DDD, respectively.

Several methods of calculating theoretical values for D_{th} were used by Nelson and Davis [4048], and the values obtained using the two methods which would be expected to give the most reliable results are given in tables 3.1 to 3.8. These methods were:

i) to calculate D_{th} from eq (7) by using values of q_m from various sources and the Maxwellian velocity distribution, and

ii) to calculate D_{th} by extrapolating measured values of W to zero field ($W_{E\rightarrow 0} = W_0$ say) and inserting W_0 in the equation $W_0/D_{th} = eE/kT$. The methods are designated q_m and W_0, respectively, in the tables and references to the source of the data on q_m or W_0 used are also included with the method.

The following references to sources of data in addition to those in the bibliography (section 5) are designated in tables 3.1 to 3.7 by the following letters:

a) D. E. Golden, Phys. Rev. **151**, 48 (1966)
b) T. F. O'Malley, Phys. Rev. **130**, 1025 (1963)
c) R. W. Crompton (unpublished).

In tables 3.1 to 3.8 values of D_{th} are given for helium, neon, argon, hydrogen, nitrogen, oxygen, carbon monoxide, and carbon dioxide. There are no published values available for krypton, xenon, nitric oxide, or air.

3.3.b. Longitudinal Diffusion Coefficient D_L

There are very few directly measured values of D_L available. For helium, argon, and carbon monoxide the only experimental data are those of Wagner, Davis, and Hurst [3313] which are shown in figure 3.1 and given in table 3.9.

At relatively low values of $E/N < 2 \times 10^{-16}$ V cm² two sets of values [1833, 3313] have been obtained for $D_L N$ for nitrogen and carbon dioxide. These are shown in figure 3.2, together with values for hydrogen obtained by Wagner et al. [3313] and values extending to very low values of E/N for oxygen obtained by Nelson and Davis [5135].

The only sets of data over an extensive range of values E/N for $E/N > 10^{-15}$ V cm² are those of Schlumbohm [1625] for hydrogen, nitrogen, oxygen, and carbon dioxide. These are shown in figure 3.3, together with two values obtained for hydrogen at $E/N \sim 10^{-15}$ V cm² obtained by Breare and von Engel [3788].

The data for $D_L N$ in the various gases are tabulated in table 3.9.

3.3.c. Transverse Diffusion Coefficient D_T

Values of the transverse diffusion coefficient are usually obtained by combining the data of sections 3.1 and 3.2, but direct measurements of D_T have recently been made for helium by Cavalleri [4049] and these are shown in figure 3.4 and table 3.10. The results are in good agreement with those obtained from the values of W and D_T/μ obtained in [2433].

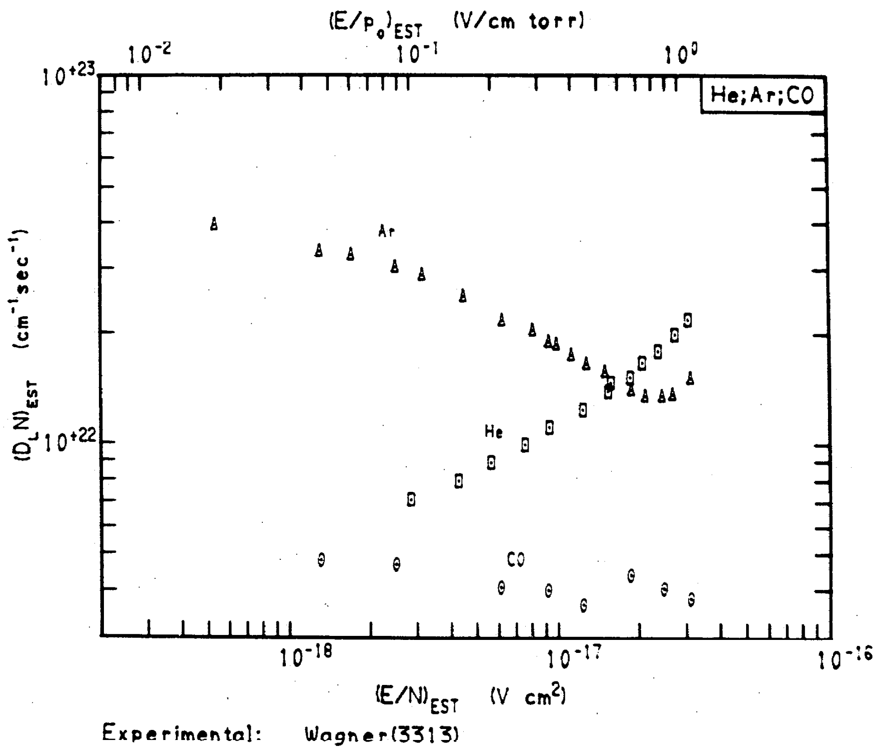
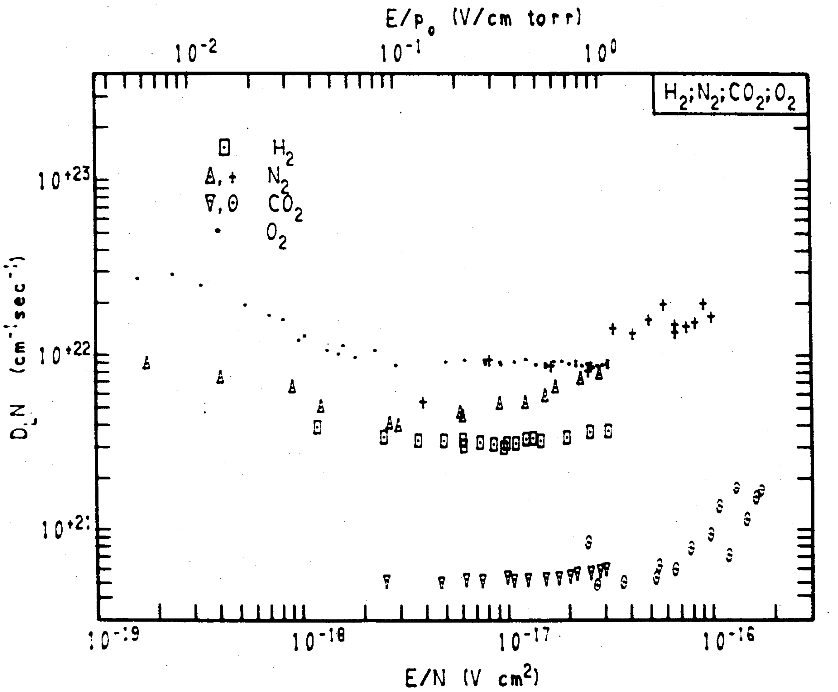
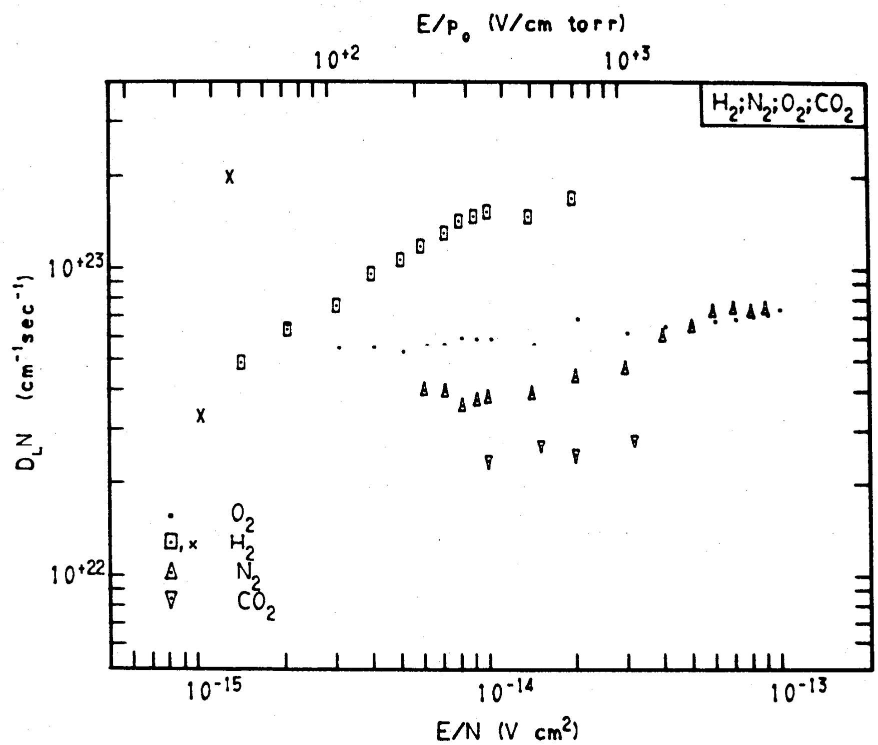


FIGURE 3.1. Experimental values of $(D_L N)_{Est}$ as a function of $(E/N)_{Est}$ for helium, argon, and carbon monoxide. (A temperature of 27 °C has been assumed to convert the values of Dp and E/p given in [3313].)



Experimental: □, Δ, ∇ Wagner(3313); ⊖, + Fink(1883); • Nelson(5135).

FIGURE 3.2. Experimental values of $D_L N$ for hydrogen, nitrogen, oxygen, and carbon dioxide for $E/N < 2 \times 10^{-16}$ V cm². (A temperature of 27 °C has been assumed to convert the values of Dp and E/p given in [3313].)



Experimental: •, □, Δ, ∇ Schlumbohm(1625); x Breare(3788).

FIGURE 3.3. Experimental values of $D_L N$ for hydrogen, nitrogen, oxygen and carbon dioxide for $E/N > 10^{-15}$ V cm². (A temperature of 20 °C has been assumed to convert the values of Dp and E/p given in [3788].)

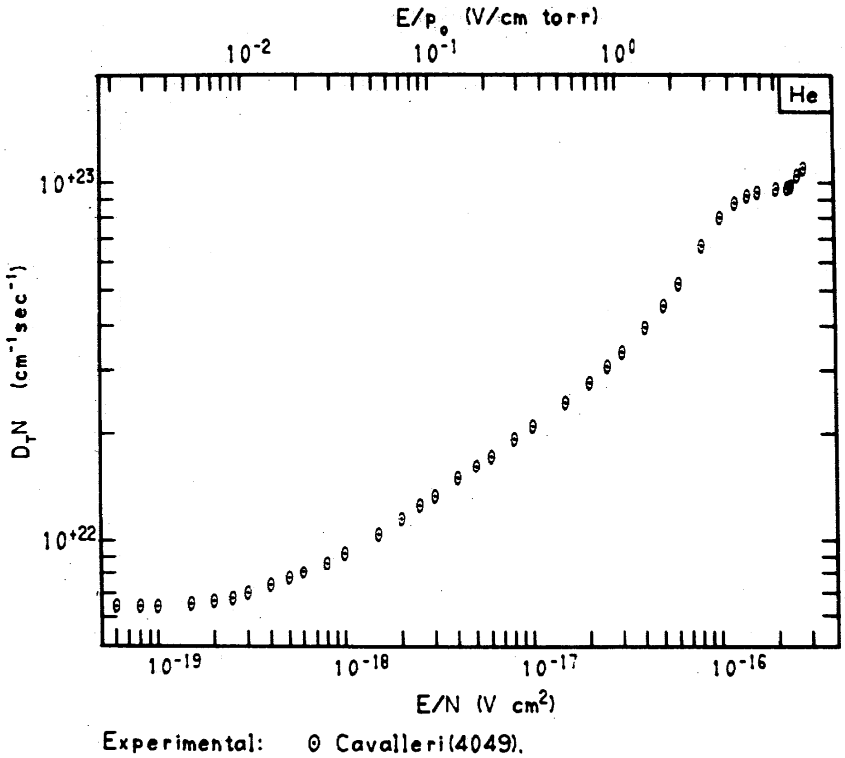


FIGURE 3.4. Experimental values of D_TN as a function of E/N for helium.

Table 3.1*

Values of $D_{th}N$ for helium

$D_{th}N(10^{21}\ cm^{-1}\ sec^{-1})$ Experimental	Theoretical	Method	Reference
6.9		DDD	Nelson (4048)
6.4		SDC	Cavalleri (4049)
	6.6	W_o(530)	Nelson (4048)
	6.6	q_m(1062)	Nelson (4048)
	6.4	q_m(2433)	Nelson (4048)
	6.9	q_m(a)	Nelson (4048)
	6.4	q_m(b)	Nelson (4048)

Table 3.2*

Values of $D_{th}N$ for neon

$D_{th}N(10^{21}\ cm^{-1}\ sec^{-1})$ Experimental	Theoretical	Method	Reference
65		DDD	Nelson (4048)
73		SDC	Cavalleri (4050)
44			Lloyd (4063)
	71	q_m(c)	Nelson (4048)
	58	q_m(b)	Nelson (4048)

Table 3.3*

Values of $D_{th}N$ for argon

$D_{th}N(10^{21}\ cm^{-1}\ sec^{-1})$ Experimental	Theoretical	Method	Reference
21		DDD	Nelson (4048)
	37	W_o(530)	Nelson (4048)
	32	q_m(1062)	Nelson (4048)
	21	q_m(b)	Nelson (4048)
	27	q_m(a)	Nelson (4048)

Table 3.4*

Values of $D_{th}N$ for hydrogen

$D_{th}N(10^{21}\ cm^{-1}\ sec^{-1})$ Experimental	Theoretical	Method	Reference
4.3		DDD	Nelson (4048)
	3.5	W_o(530)	Nelson (4048)
	3.9	q_m(1062)	Nelson (4048)

*For an outline of the methods used and the meaning of the symbols in the method column see section 3.3.a of the text.

Table 3.5*

Values of $D_{th}N$ for nitrogen

$D_{th}N(10^{21}\ cm^{-1}\ sec^{-1})$		Method	Reference
Experimental	Theoretical		
9.5		DDD	Nelson (4048)
	8.2	$W_o(530)$	Nelson (4048)
	9.8	$q_m(1062)$	Nelson (4048)

Table 3.6*

Values of $D_{th}N$ for oxygen

$D_{th}N(10^{21}\ cm^{-1}\ sec^{-1})$		Method	Reference
Experimental	Theoretical		
39		DDD	Nelson (5135)

Table 3.7*

Values of $D_{th}N$ for carbon monoxide

$D_{th}N(10^{21}\ cm^{-1}\ sec^{-1})$		Method	Reference
Experimental	Theoretical		
5.7		DDD	Nelson (4048)
	5.4	$W_o(439)$	Nelson (4048)

Table 3.8*

Values of $D_{th}N$ for carbon dioxide

$D_{th}N(10^{21}\ cm^{-1}\ sec^{-1})$		Method	Reference
Experimental	Theoretical		
0.49		DDD	Nelson (4048)
	0.47	$W_o(439)$	Nelson (4048)

*For an outline of the methods used and the meaning of the symbols in the method column see section 3.3.a. of the text.

Table 3.9(a)

Values of $D_L N$ for helium

E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1}sec^{-1})	E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1}sec^{-1})	E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1}sec^{-1})
0.2832	0.74	0.933	1.16	1.852	1.59
0.425	0.83	1.233	1.29	2.065	1.75
0.560	0.93	1.534	1.45	2.354	1.87
0.756	1.04	1.570	1.54	2.715	2.09
				3.033	2.29

Experimental:
All data taken from Wagner, et al., J. Chem. Phys. 47, 3138 (1967).

Table 3.9(b)

Values of $D_L N$ for argon

E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1}sec^{-1})	E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1}sec^{-1})	E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1}sec^{-1})
0.0531	4.2	0.620	2.29	1.487	1.66
0.1298	3.5	0.809	2.16	1.871	1.47
0.1711	3.5	0.927	2.01	2.106	1.42
0.2478	3.2	0.985	1.99	2.425	1.42
0.312	3.1	1.121	1.85	2.655	1.43
0.442	2.7	1.275	1.75	3.08	1.60

Experimental:
All data taken from Wagner, et al., J. Chem. Phys. 47, 3138 (1967).

Table 3.9(c)

Values of $D_L N$ for hydrogen

E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1}sec^{-1})	E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1}sec^{-1})	E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1}sec^{-1})
0.1180	0.40 (a)	1.104	0.33 (a)	204.2	6.3 (c)
0.2478	0.36 (a)	1.239	0.35 (a)	302	7.6 (c)
0.366	0.34 (a)	1.346	0.35 (a)	398	9.5 (c)
0.489	0.34 (a)	1.457	0.34 (a)	501	10.6 (c)
0.608	0.35 (a)	1.959	0.36 (a)	589	11.7 (c)
0.613	0.32 (a)	2.537	0.38 (a)	708	13.0 (c)
0.737	0.33 (a)	3.10	0.39 (a)	794	14.2 (c)
0.856	0.33 (a)	103.1	3.3 (b)	891	14.7 (c)
0.968	0.31 (a)	130.3	20. (b)	1000	15.3 (c)
0.991	0.33 (a)	141.3	4.9 (c)	1380	14.7 (c)
				1950	16.9 (c)

Experimental:
(a) Wagner, et al., J. Chem. Phys. 47, 3138 (1967).
(b) Breare, et al., Proc. Roy. Soc. (London) Ser. A 282, 390 (1964).
(c) Schlumbohm, Z. Physik, 184, 492 (1965).

Table 3.9(d)

Values of $D_L N$ for nitrogen

E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1} sec^{-1})	E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1} sec^{-1})	E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1} sec^{-1})
0.01769	0.96 (a)	1.716	0.70 (a)	603	4.0 (c)
0.0403	0.79 (a)	2.278	0.79 (a)	708	4.0 (c)
0.0900	0.70 (a)	2.491	0.81 (b)	813	3.6 (c)
0.1241	0.54 (a)	2.809	0.84 (a)	912	3.8 (c)
0.2670	0.43 (a)	3.28	1.4 (b)	1000	3.8 (c)
0.2949	0.42 (a)	4.13	1.3 (b)	1413	4.0 (c)
0.385	0.53 (b)	4.93	1.6 (b)	1995	4.5 (c)
0.590	0.50 (a)	5.82	2.0 (b)	2951	4.7 (c)
0.608	0.47 (a)	6.59	1.3 (b)	3981	6.1 (c)
0.819	0.94 (b)	6.62	1.5 (b)	5012	6.6 (c)
0.922	0.56 (a)	7.46	1.5 (b)	5888	7.4 (c)
1.226	0.57 (a)	8.26	1.5 (b)	6918	7.6 (c)
1.536	0.62 (a)	9.11	2.0 (b)	7943	7.4 (c)
1.639	0.86 (b)	9.87	1.7 (b)	8913	7.6 (c)

Experimental:
(a) Wagner, et al., J. Chem. Phys. 47, 3138 (1967).
(b) Fink, et al., Helv. Phys. Acta. 38, 717 (1965).
(c) Schlumbohm, Z. Physik 184, 492 (1965).

Table 3.9(e)

Values of $D_L N$ for oxygen

E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1} sec^{-1})	E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1} sec^{-1})	E/N (10^{-17} Vcm^2)	$D_L N$ (10^{22} cm^{-1} sec^{-1})
0.00400	3.6	0.2278	1.06	1.855	0.93
0.01606	2.7	0.2889	0.87	2.011	0.90
0.02351	2.9	0.502	0.91	2.168	0.87
0.0329	2.5	0.621	0.94		0.92
0.0533	1.95	0.778	0.93	2.318	0.88
0.0700	1.68	0.784	0.90	2.462	0.89
0.0818	1.60	0.928	0.91	2.550	0.90
0.0975	1.21	0.934	0.88		0.85
0.1044	1.29	1.091	0.92	2.625	0.85
0.1338	1.06	1.241	0.95	2.775	0.87
0.1522	1.01	1.397	0.88	2.919	0.88
0.1595	1.14	1.548	0.90	3.08	0.90
0.1832	0.96	1.554	0.86	3.10	0.94
		1.705	0.93		0.86

Experimental:
All data taken from Nelson, et al., J. Chem. Phys. 57, 4079 (1972).

Table 3.9(f)

Values of D_LN for carbon monoxide

E/N (10^{-17} Vcm^2)	D_LN (10^{22} cm^{-1}sec^{-1})	E/N (10^{-17} Vcm^2)	D_LN (10^{22} cm^{-1}sec^{-1})	E/N (10^{-17} Vcm^2)	D_LN (10^{22} cm^{-1}sec^{-1})
0.1295	0.50	0.612	0.43	1.855	0.46
0.2474	0.49	0.913	0.42	2.474	0.43
		1.231	0.39	3.10	0.40

Experimental:
All data taken from Wagner, et al., J. Chem. Phys. 47, 3138 (1967).

Table 3.9(g)

Values of D_LN for carbon dioxide

E/N (10^{-17} Vcm^2)	D_LN (10^{22} cm^{-1}sec^{-1})		E/N (10^{-17} Vcm^2)	D_LN (10^{22} cm^{-1}sec^{-1})		E/N (10^{-17} Vcm^2)	D_LN (10^{22} cm^{-1}sec^{-1})	
0.2532	0.053	(a)	2.067	0.056	(a)	7.76	0.079	(b)
0.471	0.051	(a)	2.168	0.058	(a)	9.73	0.094	(b)
0.625	0.054	(a)	2.441	0.083	(b)	10.73	0.14	(b)
0.748	0.054	(a)	2.526	0.059	(a)	11.87	0.072	(b)
0.989	0.055	(a)	2.709	0.048	(b)	12.94	0.18	(b)
1.078	0.053	(a)	2.763	0.061	(a)	14.65	0.11	(b)
1.254	0.054	(a)	2.827	0.060	(a)	16.25	0.15	(b)
1.508	0.057	(a)	3.02	0.061	(a)	17.26	0.17	(b)
1.537	0.055	(a)	3.68	0.050	(b)	1000	2.32	(c)
1.766	0.055	(a)	5.32	0.054	(b)	1513	2.63	(c)
2.008	0.056	(a)	5.45	0.063	(b)	1995	2.43	(c)
			6.52	0.060	(b)	3162	2.74	(c)

Experimental:
(a) Wagner, et al., J. Chem. Phys. 47, 3138 (1967).
(b) Fink, et al., Helv. Phys. Acta. 38, 717 (1965).
(c) Schlumbohm, Z. Physik 184, 492 (1965).

Table 3.10

Experimental values of D_TN for helium

E/N (10^{-17} Vcm^2)	D_TN (10^{23} cm^{-1}sec^{-1})	E/N (10^{-17} Vcm^2)	D_TN (10^{23} cm^{-1}sec^{-1})	E/N (10^{-17} Vcm^2)	D_TN (10^{23} cm^{-1}sec^{-1})
0.00600	0.064	0.1500	0.104	3.00	0.34
0.00800	0.064	0.2000	0.115	4.00	0.40
0.01000	0.065	0.2500	0.125	5.00	0.46
0.01500	0.066	0.300	0.133	6.00	0.52
0.02000	0.067	0.400	0.149	8.00	0.67
0.02500	0.068	0.500	0.162	10.00	0.80
				12.00	0.88
0.0300	0.070	0.600	0.173		
0.0400	0.074	0.800	0.193	14.00	0.92
0.0500	0.078	1.000	0.209	16.00	0.94
0.0600	0.081	1.500	0.244	20.00	0.96
0.0800	0.087	2.000	0.277	23.00	0.97
0.1000	0.092	2.500	0.31	24.00	0.98
				26.00	1.05
				28.00	1.10

Experimental:
All data taken from Cavalleri, Phys. Rev. 179, 186 (1969).

3.4. Attachment Coefficient

By definition, electronegative gases are those that form stable negative ions in an energy state lower than that of the ground state of the neutral atoms or molecules of the gas. The process of adding the extra electron to form the negative ion is known as electron attachment, and requires the removal not only of any kinetic energy that the electron may possess, but also of the energy difference between the original state of the neutral atom or molecule and the negative ion. The energy may be removed in a variety of ways, so giving rise to processes of

i) radiative attachment, represented by the equation

$$A+e \rightarrow A^- + h\nu,$$

ii) dissociative attachment, represented by the equation

$$AB+e \rightarrow A^- + \text{k.e.},$$

iii) three-body attachment, represented by the equation

$$A+B+e \rightarrow A^- + B + \text{k.e.},$$

iv) dissociation into ions, represented by the equation

$$AB+e \rightarrow A^- + B^+ + e + \text{k.e.}.$$

Here A and B represent atoms, e an electron, A^- and B^+ negative and positive ions, respectively, and k.e., kinetic energy.

In general, when an electron swarm moves through an electronegative gas all four attachment processes are possible, although process (i) usually has a relatively small cross section and process (iv) is a high energy process so that these two processes are often negligible. The result of all these processes is that electrons are continually removed from the swarm to form negative ions.

When the value of E/N is sufficiently small, the mean energy of the electrons is so low that ionization by electrons in the high energy tail of the distribution is negligible. In these circumstances, a steady electron current, I_0, released into a uniform field (by external illumination of a cathode of a uniform field electrode system by ultraviolet illumination, say) results, after travelling a distance, d, through the gas in the field direction, in an electron current

$$I_- = I_0 e^{-\eta d},$$

where η is an attachment coefficient representing all the possible attachment processes. Under these conditions, η can be determined [see e.g. 1317] by measuring the electron current as a function of d at a given value of N. Alternatively, a short duration pulse of electrons released from the cathode gives rise to an exponential distribution of negative ions across the gap, which, after the disappearance of the electrons into the anode, gives an ion current of the form

$$I_0' e^{\eta W_i t},$$

where I_0' is a constant for a given gas, pressure, and electrode system and W_i is the negative ion drift velocity. Thus sampling the negative ion current arriving at a given distance from the cathode as a function of time [see e.g. 1383] gives values of η.

Values of η have also been determined [see e.g. 649] by measuring the transverse diffusion of a mixed swarm of electrons and negative ions at various distances from a point source.

These methods give values of η/N as a function of E/N which by carrying out experiments at sufficiently low E/N, can be extrapolated and used to obtain values of the attachment rate coefficient at thermal energies, which is the coefficient obtained directly from experiments on plasma decay using microwave methods.

Whether three-body attachment is a significant process in any given case may be determined by carrying out the measurements of the attachment coefficient over a range of gas pressures, because the three-body attachment coefficient depends on N^2 whereas the coefficients representing the other attachment processes are linearly dependent on N.

The situation becomes much more complicated at higher values of E/N, where in addition to electron attachment, ionization by electrons and detachment of electrons from negative ions in collisions with gas molecules both have to be taken into account and where ion conversion reactions may also be important. The resulting equation for the total current at a distance, d, in the direction of a uniform field from a cathode from which a steady initial electron current, I_0, is released is given in section 3.7.c as equation (16). This equation is such that analysis of experimental data on I versus d to give significant values of the individual coefficients (including the attachment coefficient) is extremely difficult in many cases and the values obtained depend on the simplifying assumptions that are found to be necessary. Similar complications have, of course, to be taken into account in the analysis of experiments on the temporal development of pulses of electrons released from the cathode.

Of the gases for which data are included in this survey, only oxygen, carbon monoxide, nitric oxide, carbon dioxide, and air are electronegative and the values of η/N for these gases are given in the following graphs and tables.

3.4.a. Attachment Coefficient—Oxygen

At low values of E/N ($< 12 \times 10^{-17}$ V cm^2), Chanin, Phelps, and Biondi [131, 1383], using a drift tube in which the negative ion current resulting from the release of electrons from the cathode by a pulse of ultraviolet light was sampled as a function of time, established that η/N was a function of N as well as of E/N, indicating that in this region, a three-body attachment process is significant. Their results are shown in figure 4.1(a) as (eta/N), E/N (eta on the graphs $\equiv \eta$ in text) together with another set of results obtained using a drift tube with electrical shutters [1269] covering approximately the same range. The range of gas number densities covered was extended in later experiments in which the development of an electron avalanche was measured oscillographically [4919] with the results shown in figure 4.1(b). To avoid confusion in the graphs, the three values obtained in [1006] that also show the dependence of η on N^2 are omitted from the figures but included in table 4.1 where the results of all these investigations are given as values of η/N^2.

Measurements of attachment in oxygen have also been made by studying plasma decay by microwave methods. This procedure gives attachment rate coefficients at thermal energies. For comparison, rate coefficients at thermal energies can also be obtained from the drift-tube data using the procedure given below.

As discussed in section 2.1,

$$\eta W = a_3 N^2,$$

where a_3 is the three-body attachment rate coefficient. Thus by using the data given in figure 4.1, together with data for W such as that given in section 3.1 values of a_3 can be obtained as a function of E/N. Further, using data for D/μ such as that given in section 3.2, values of a_3 as a function of characteristic energy can be obtained. Extrapolation of the values of a_3 to thermal energy can then be made. Values of a_3 as a function of E/N can also be obtained from drift-tube measurements in gas mixtures. In this case

$$\eta W = \sum_X a_3(X) N(X) N(O_2),$$

where X indicates the various gases in the mixture and $N(X)$ the number density of molecules of gas X, so that a_3 for oxygen in different gases can be determined by measuring η for various small admixtures of O_2 in, say, N_2 or He.

Using values of W and D/μ given in their papers, Chanin et al. [1383] and Pack and Phelps [1662] used the above procedure to obtain the values of a_3 at thermal energies shown in table 4.2.

As can be seen from figure 4.2, the results in [1383] and [1662] for oxygen at low energies for $T=300$ K are in general agreement with the recent data of McCorkle et al. [5046]. The discrepancy at higher energies, together with a similar discrepancy between results obtained with N_2 as the third body, suggests however, that the energy scale of [1383] and [1662] is in error. The results of recent microwave measurements [762, 1633, 4097, 5131, 5770, 5125] are also given in table 4.2, and it can be seen that values of a three-body attachment rate coefficient at 300 K in close agreement with the extrapolated drift-tube data are obtained, although in earlier microwave experiments [4095, 711, 4096] a two-body attachment rate coefficient of about 1.4×10^{-15} cm^3 s^{-1} was reported.

As can be seen from figure 4.3, recent beam experiments [5047] and theoretical calculations show considerable structure, in the curves of three-body rate coefficient for the production of O_2^- as a function of electron energy, which was not revealed by the swarm data. The curves shown in figure 4.3 have been normalized at the peak of the swarm data given in [1383]. The envelope of these curves follows closely the swarm results shown in figure 4.2, for energies up to about 0.6 eV. At higher energies the swarm data are higher because of the effect of the much wider energy distribution in the swarm. The first peak of the beam data also shows a smaller dependence on temperature than the peak of the swarm data.

In the intermediate range of values of E/N between about 12×10^{-17} and 84×10^{-17} V cm^2 a relatively large number of experimental investigations have been carried out using the various methods outlined in the introduction to this section. In this region of E/N, it is found that η/N is a function of E/N only, which indicates the predominance of two-body attachment over the range of values of N studied. Ionization is negligibly small at values of E/N up to about 56×10^{-17} V cm^2, but above this value it becomes increasingly significant, and the coefficient measured by these methods is then $(\eta - \alpha)/N$ rather than η/N.

Many of the early data [1317, 1336, 2093] were expressed as values of h, the probability of attachment in a collision, which makes the recovery of accurate values of η/N difficult, because it involves the use of numerical values of other parameters such as W which were in some cases taken from different papers; e.g., values of W given in figure 1.28 were used in the case of [1317] and the values of k given in [195] in the case of [1336]. Moreover, temperatures to which the values of E/p given in [1317, 1433, 649, and 2093] correspond are not clearly stated and have been assumed to be 20°C. These factors possibly account for some of the scatter of the data shown in figures 4.4(a) and 4.4(b), but an analysis [1006] of the sources of error in the various experiments shows that most of the scatter is likely to be experimental in origin; for example, electron diffusion could have given rise to errors in some of the results given in [1433] and [1317], and the length of the pulse used in [1336] was such that it would be likely to lead to values of η/N which were too low.

Only the results of recent experimental work in which the results are given as η/N, E/N without ambiguity are given in table 4.3. The results of theoretical computations [2553] of η/N, using two slightly different sets of cross sections chosen to fit these and other (see sec. 3.1.1 and sec. 3.7.d) swarm data, are given in figures 4.4(a) and 4.4(b) to help comparison of the results.

For values of E/N above 84×10^{-17} V cm^2 the ionization coefficient increases rapidly, becoming greater than the attachment coefficient at about 10^{-15} V cm^2. Many attempts have been made to determine the attachment coefficient from the spatial growth of ionization at constant values of E/N in this region. The appropriate equation for the analysis of the results is eq (16), but its use presents formidable problems. The experimental data in all cases show the effect of attachment through the departure of the $\ln I$, d graphs from linearity at low values of d, but the values obtained for the attachment coefficient depend on the assumptions made about which processes are significant; e.g., detachment and ion conversion are often assumed to be negligible. Furthermore, in oxygen as in air [2047], analysis of typical experimental data in which the ionization currents are measured to within 2 or 3 percent shows that the spread of attachment coefficients that will fit the experimental data is very large (typically ~100 percent). This situation is reflected in the wide range of values for η/N that have been obtained. These are shown in figure 4.5. The results of an investigation of the development of the current with time resulting from a short burst of electrons released from the cathode in a plane parallel gap [2370] are also shown in figure 4.5. Again there are considerable complications in the analysis and the results for η/N lie close to the lower limit of those obtained from spatial growth measurements in the region where they overlap. It is clear from consideration of these data that the value of the attachment coefficient in the region where ionization is significant is at present known only in order of magnitude because of the complexities in the reaction scheme for oxygen.

3.4.b. Attachment Coefficient—Nitric Oxide

The only published values of the attachment coefficient as a function of E/N for nitric oxide are those recently obtained by Parkes and Sugden [4943], whose data at 293 K are shown in figure 4.6 and tabulated in table 4.4. The earlier data of Bradbury [2099] for $25\times10^{16}<N<100\times10^{16}$ cm^{-3} were given as values of h, the probability of attachment, and require values of V to convert them to values of the attachment coefficient (such as those shown in fig. 4.6) for comparison with the recent data. The data of Parkes and Sugden were obtained from measurements on the electron and ion pulses resulting from the release of a pulse of electrons from a cathode of a drift tube at relatively high number densities in the range $2.2\times10^{18}<N<5.25\times10^{18}$ cm^{-3}. As can be seen from figure 4.6, all their results lie on a single curve of η/N^2, E/N, showing that three-body attachment occurs in this case, which is in agreement with the earlier work of Bradbury [2099] and with recent studies of plasma decay using the microwave method [1608, 3229, 3610].

Extrapolation of the drift-tube data of Parkes and Sugden to thermal energies, however, gives a value of $(8\pm2)\times10^{-31}$ cm^6 s^{-1} for the thermal attachment rate coefficient which is much higher than the values 1.3 to 2.2×10^{-31} cm^6 s^{-1} obtained in the microwave experiments at low values of N. Further measurements [4943] of mass analyzed ion currents in NO, O_2, and NO/O_2 mixtures at low values of $N\sim3\times10^{16}$ cm^{-3} showed that the attachment rates obtained in the microwave experiments are too low because of the neglect of detachment. Detachment becomes less significant as the number density is increased because of the conversion of the NO^- ions from which electrons are readily detached to more stable ions in the processes

$$NO^- + 2NO \rightarrow NO_2^- + N_2O$$

or

$$NO^- + 2NO \rightarrow N_2O_2^- + NO$$

$$N_2O_2^- + NO \rightarrow NO_2^- + N_2O.$$

Both the microwave and drift-tube experiments show that the attachment coefficient decreases markedly with increasing temperature. The drift-tube experiments show, however, that the temperature dependence is larger at lower number densities over the range investigated, indicating that the situation is again complicated by detachment.

3.4.c. Attachment Coefficient—Carbon Monoxide

All the possible processes of attachment in carbon monoxide are dissociative processes with relatively high energy thresholds (>9.5 eV) (Hagstrum, Rev. Mod. Phys. **23**, 185, 1951; Chantry, Phys. Rev. **172**, 125, 1968). This, together with the fact that there is a very rapid detachment reaction between the O^- ions formed and CO to give CO_2 makes attachment unlikely to be significant under swarm conditions. The importance of this effect was illustrated (i) by mass spectrometric measurements [3352] (see also J. L. Moruzzi and A. V. Phelps, J. Chem. Phys. **45**, 4617, 1966) at relatively low gas number densities (3.3×10^{16} to 16.5×10^{16} cm^{-3}) which showed negligible negative ion formation for $1.5\times10^{-17}<E/N<300\times10^{-17}$ V cm^2, (ii) by measurements [2099, 2408] of the negative ion component of drifting electron swarms by means of a radio-frequency electron filter of the Bradbury type which gave no detectable attachment coefficient for $6.4\times10^{16}<N<31.5\times10^{16}$ cm^{-3} for E/N in the range from 14×10^{-17} to 118×10^{-17} V cm^2, and (iii) by measurements of prebreakdown ionization [4016] at relatively high gas number density (94×10^{16} to 321×10^{16} cm^{-3}) which gave no measurable attachment coefficient for $122\times10^{-17}<E/N<182\times10^{-17}$ V cm^2; earlier measurements [1254] seemed to show attachment in CO but the observed attachment has since been shown [5243] to be due to impurities.

3.4.d. Attachment Coefficient—Carbon Dioxide

The published results on values of attachment coefficients in carbon dioxide are shown in figure 4.7. No dependence of the coefficient η/N on N has been found, indicating that attachment occurs by a two-body process of associative detachment.

The experimental results shown in figure 4.7 for $E/N < 73 \times 10^{-17}$ V cm^2 were obtained [2408] for a range of values of N from 14×10^{16} to 28×10^{16} cm^{-3} by determining the negative ion component of a drifting swarm using a radio-frequency electron filter of the Bradbury type. Those for $E/N > 73 \times 10^{-17}$ V cm^2 were obtained either by analysis of the measured spatial growth of prebreakdown ionization [948, 3435, 4843] in the steady state for $78 \times 10^{16} < N < 386 \times 10^{16}$ cm^{-3} or by analysis of oscillographic observations of prebreakdown current pulses [1724]. Theoretical values [2553] obtained using cross sections obtained from consideration of swarm data are also shown.

The mean values given in figure 4.7 should not be taken as indicating more than approximate values of the attachment coefficient, because the nature of the analysis of the experimental data is such that a considerable spread (often greater than 100 percent) about the mean values given would be compatible with the experimental results.

3.4.e. Attachment Coefficient—Air

In air ionization becomes significant with respect to attachment at a value of E/N above about 70×10^{-17} V cm^2, so that it is convenient to consider the results obtained in two regions above and below this value of E/N.

The values obtained in the lower region of E/N are given in figure 4.8. All these results were obtained using various arrangements for the spatial analysis of an electron swarm moving through the gas, except for those in [3165] in which the temporal development of avalanches was measured. One of the sets of data [1317] was presented in the form of values of the probability of attachment, h, at an unspecified temperature, so that the conversion to η and the assumption of a temperature of 20 °C might have introduced some error in this case, but it seems likely that the spread in the other results arises from experimental factors such as those mentioned in the case of oxygen.

It is interesting to note that at very low E/N below about 10×10^{-17} V cm^2 the dependence of η/N on N observed by Hessenauer [3165] indicates the predominance of three-body attachment as in oxygen, the values for η/(partial pressure of oxygen) in air lying close to the values of η/p obtained in oxygen alone.

Thermal attachment rate coefficients have been obtained for air [762] in the range $10^{17} < N < 10^{18}$ cm^{-3} and for 4:1 nitrogen/oxygen mixtures [5770] in the range $3.54 \times 10^{16} < N < 3.54 \times 10^{17}$ cm^{-3} from microwave studies of the decay of ionization produced by pulsed electron beams. The results of Brodski and Zagik [762] were given in the form of a graph of $\nu_a/[O_2]$ versus p which tended to saturate at the higher pressures. Treating the low pressure part of the curve as linear, gave $k_1 = 3 \times 10^{-30}$ cm^6 s^{-1} and k_2 as 5×10^{-31} cm^6 s^{-1}, where k_1 and k_2 are defined by

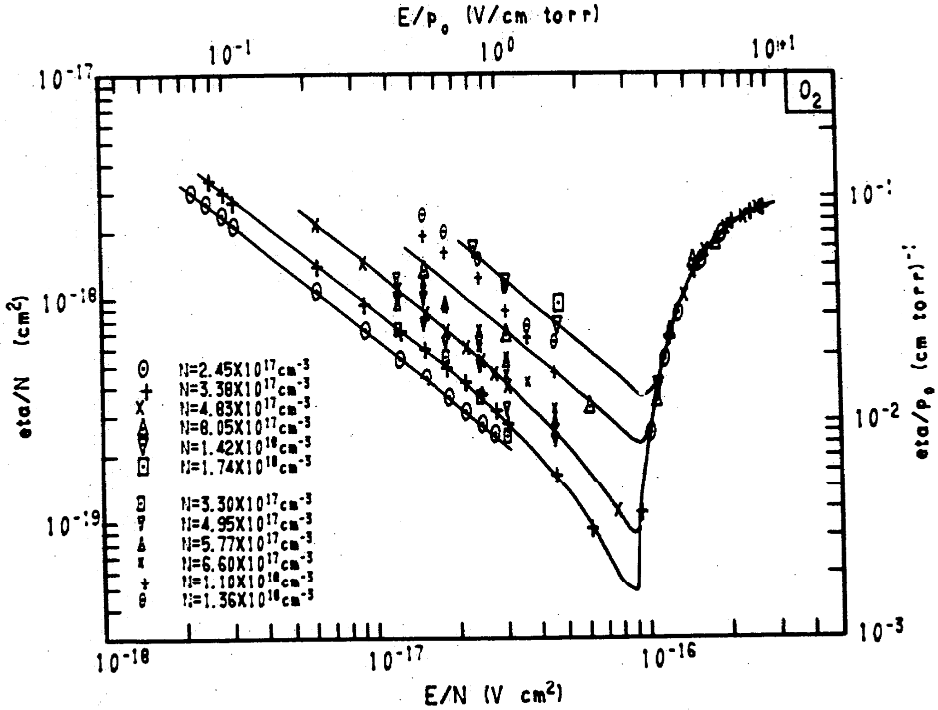
$$\nu_a/[O_2] = k_1[O_2] + k_2[N_2],$$

the brackets indicating concentrations. The results of Hirsh, Eisner, and Slevin [5770] showed that ν_a was linearly dependent on pressure over the range investigated and gave a value of $k_3 = 1.1 \times 10^{-31}$ cm^6 s^{-1}, where k_3 is defined by

$$\nu_a = k_3([O_2] + [N_2])^2.$$

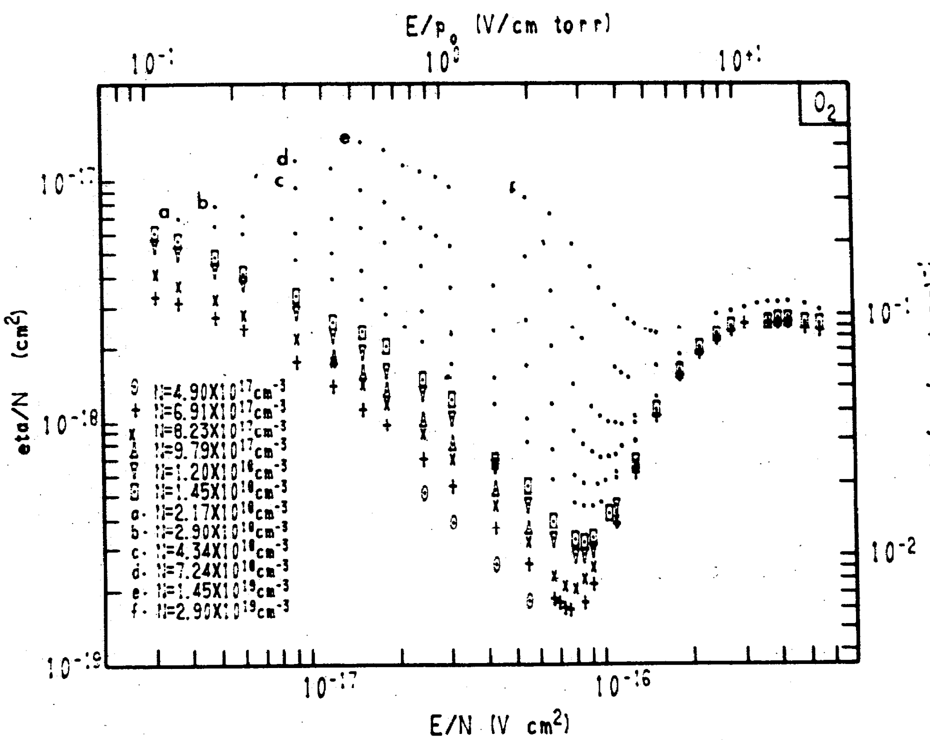
In air $k_3 = k_1 + 4k_2/25$, so that the value of k_3 from the results in [762] is 1.4×10^{-31} cm^6 s^{-1} in fair agreement with the value given in [5770].

The values for η/N at higher values of E/N when ionization becomes significant are shown in figure 4.9. Similar difficulties concerning the analysis of the experimental data arise as were discussed in the case of oxygen and these account for the lack of precise knowledge of the attachment coefficient in these conditions.



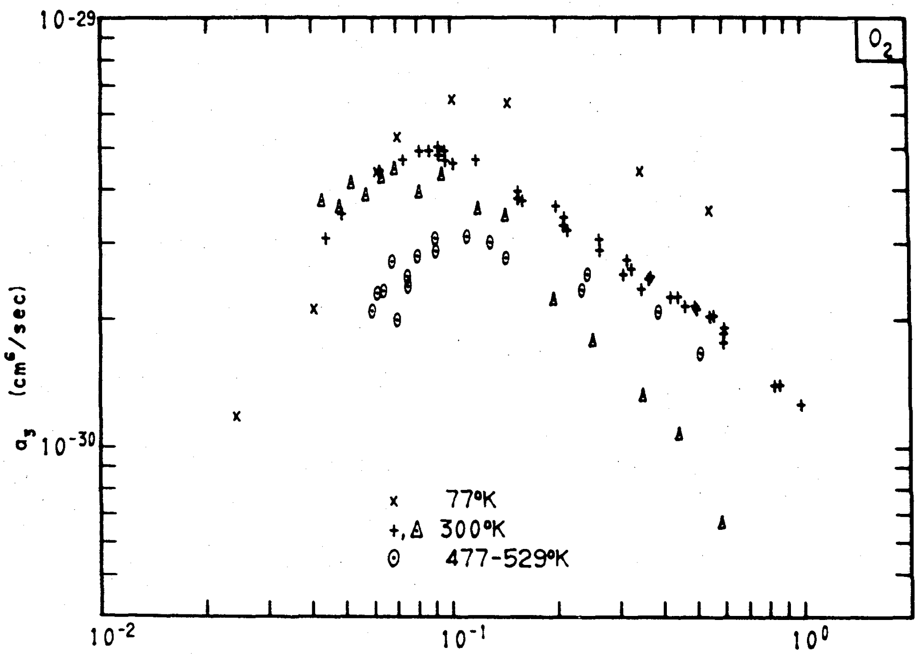
Experimental: Small symbols, Rees(1269);
Large symbols and lines, Chanin(1383).

FIGURE 4.1(a). Experimental values of η/N, E/N for oxygen at low values of E/N for $2.45\times10^{17} < N < 1.74\times10^{18}$ cm^{-3}.



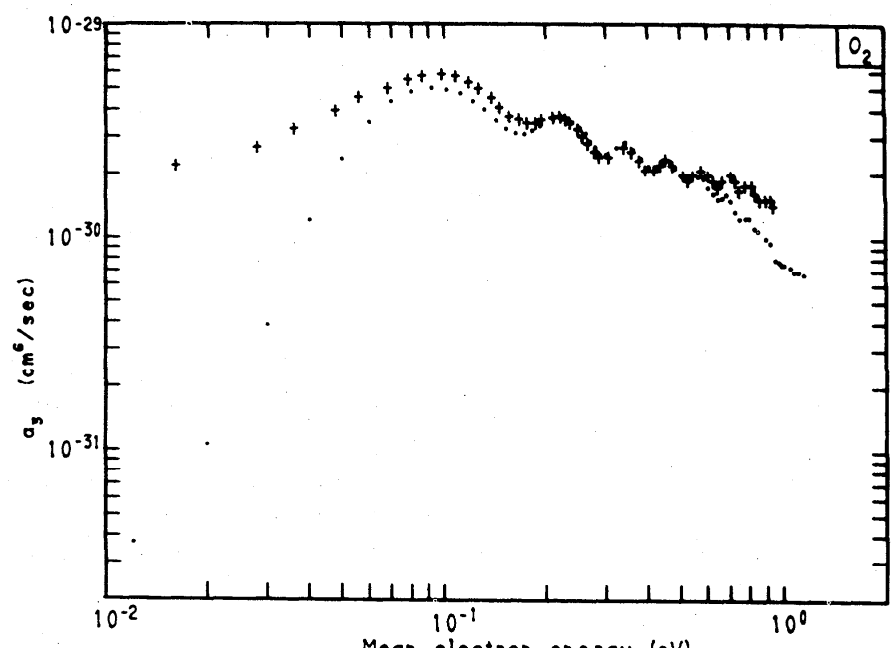
Experimental: Grunberg(4919).

FIGURE 4.1(b). Experimental values of η/N, E/N for oxygen at low values of E/N for $4.90\times10^{17} < N < 2.9\times10^{19}$ cm^{-3}.



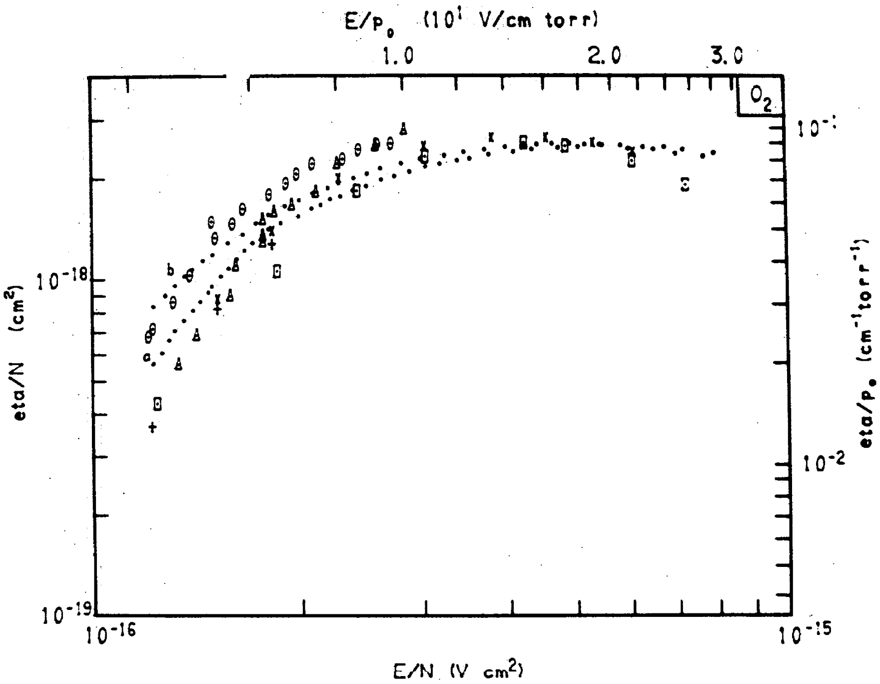
Experimental: x,+ Chanin(1383); ʘ Pack(1662); Δ McCorkle(5046).

FIGURE 4.2. Three-body attachment rate coefficient for oxygen as a function of mean electron energy at various temperatures.



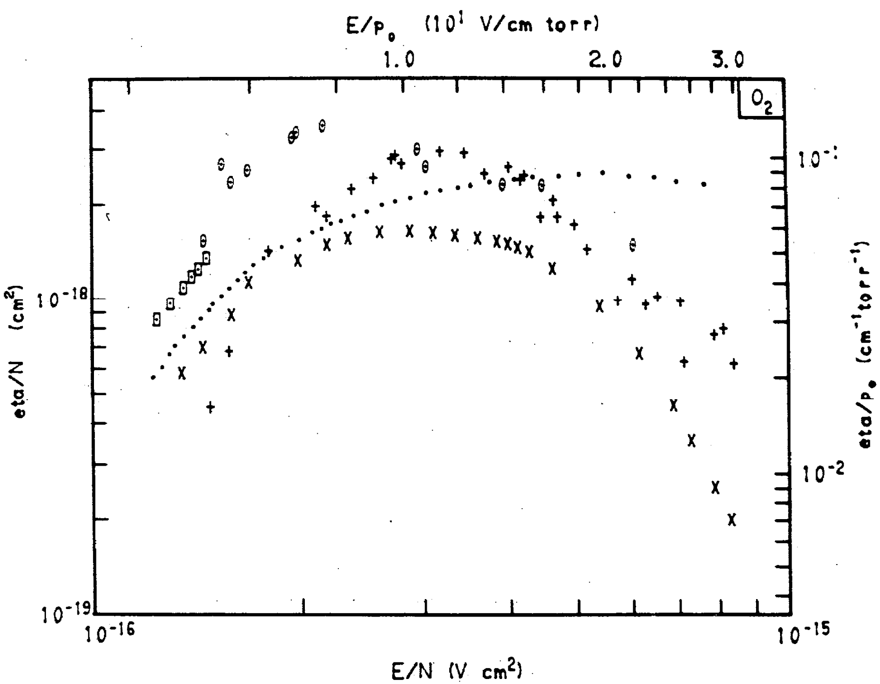
Experimental: • Spence(5047).
Theoretical: + Chapman and Herzenberg as given in Spence(5047).

FIGURE 4.3. Comparison of the results of beam experiments on the three-body attachment rate coefficient as a function of electron energy for oxygen at 300 K with the maximum theoretically computed values. (The experimental beam results were normalized at the peak of the swarm data given in [1383] and the theoretical data to the second peak of the experimental beam results.)



Experimental: Θ Chanin(1383); + Rees(1269); x Huxley(649); ⊟ Chatterton(1006); Δ Doehring(727).
Theoretical: •a, •b Hake(2553).

FIGURE 4.4(a). Values of η/N, E/N for oxygen for $12\times10^{-17} < E/N < 84\times10^{-17}$ V cm^2. (The experimental data for $E/N > 56\times10^{-17}$ V cm^2 represent values of $(\eta-\alpha)/N$.)



Experimental: Θ Bradbury(1317); X Herreng(1336); + Kuffel(1433); ⊟ Cravath(2093).
Theoretical: • Hake(2553).

FIGURE 4.4(b). Values of η/N, E/N for oxygen for $12\times10^{-17} < E/N < 84\times10^{-17}$ V cm^2. (The experimental data for $E/N > 56\times10^{-17}$ V cm^2 represent values of $(\eta-\alpha)/N$.)

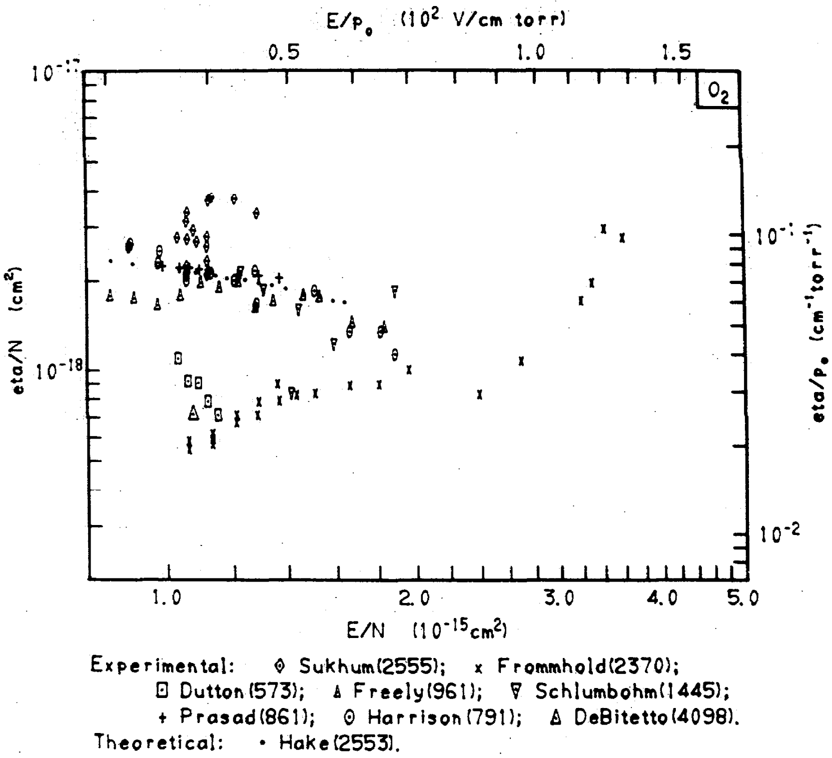


FIGURE 4.5. Values of η/N, E/N for oxygen at $E/N > 84 \times 10^{-17}$ V cm².

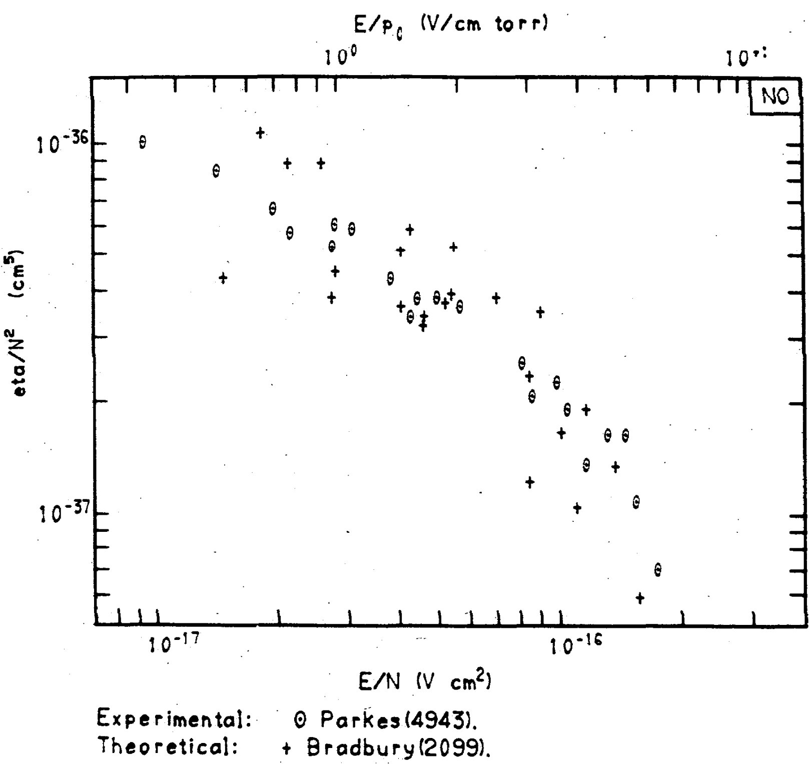
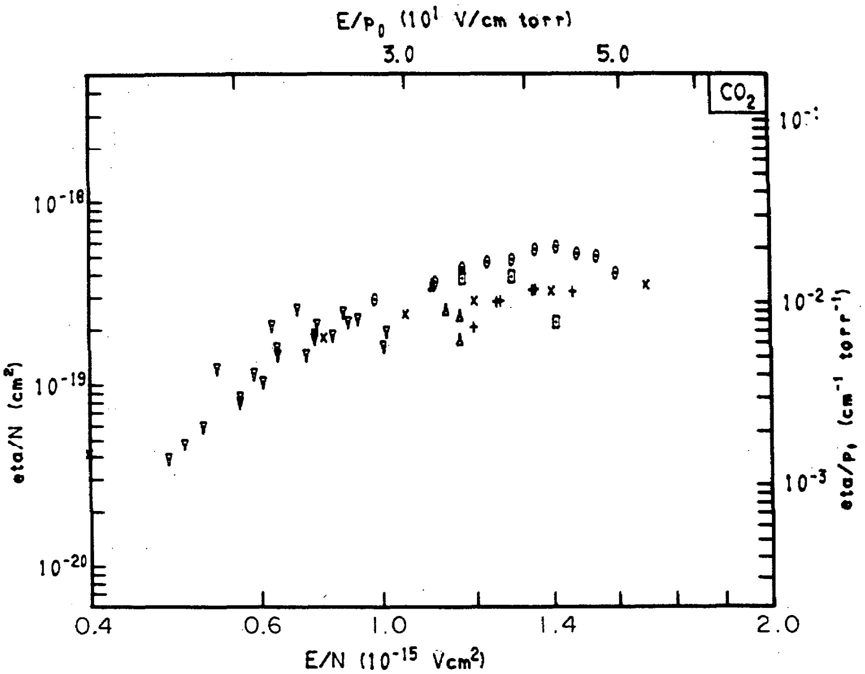
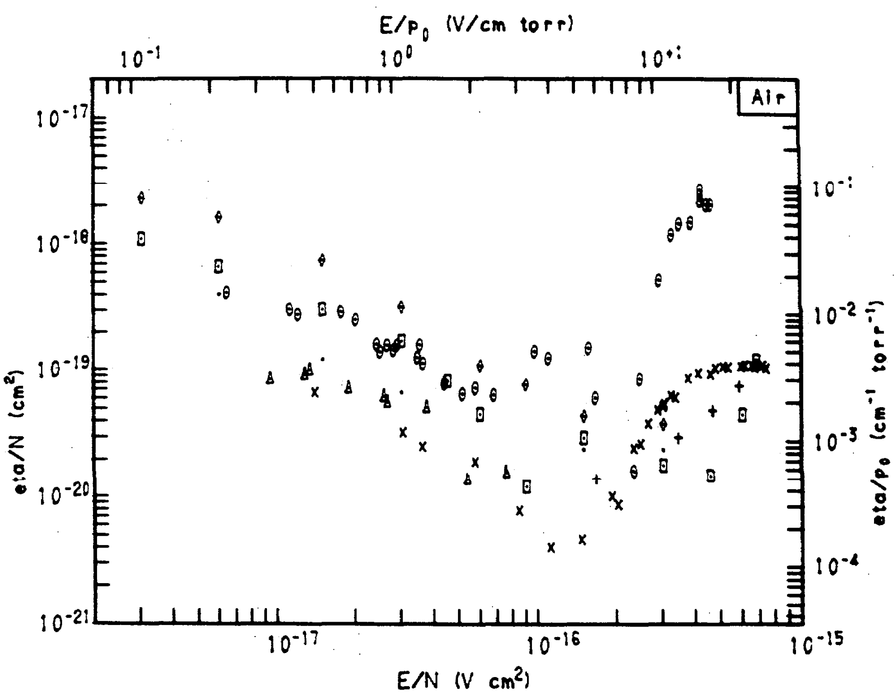


FIGURE 4.6. Values of η/N^2, E/N for nitric oxide. (The values of Bradbury [2099] were obtained from the published values of the probability of attachment using the assumption $W = W_M$ and the values of W_M given in fig. 1.32.)



Experimental: ⊖ Bhalla(948); + Schlumbohm(1724);
∇ Chatterton(2408); ⊡ Conti(3435); Δ Davies(4843).
Theoretical: x Hake(2553).

FIGURE 4.7. Values of η/N, E/N for CO_2.



Experimental: ⊖ Bradbury(1317); Δ Bailey(1332;2953);
x Kuffel(1433) + Chatterton(2408);
•,⊡,⊕ Hessenauer(3165).

FIGURE 4.8. Experimental values of the attachment coefficient for air for $E/N < 68 \times 10^{-17}$ V cm^2.

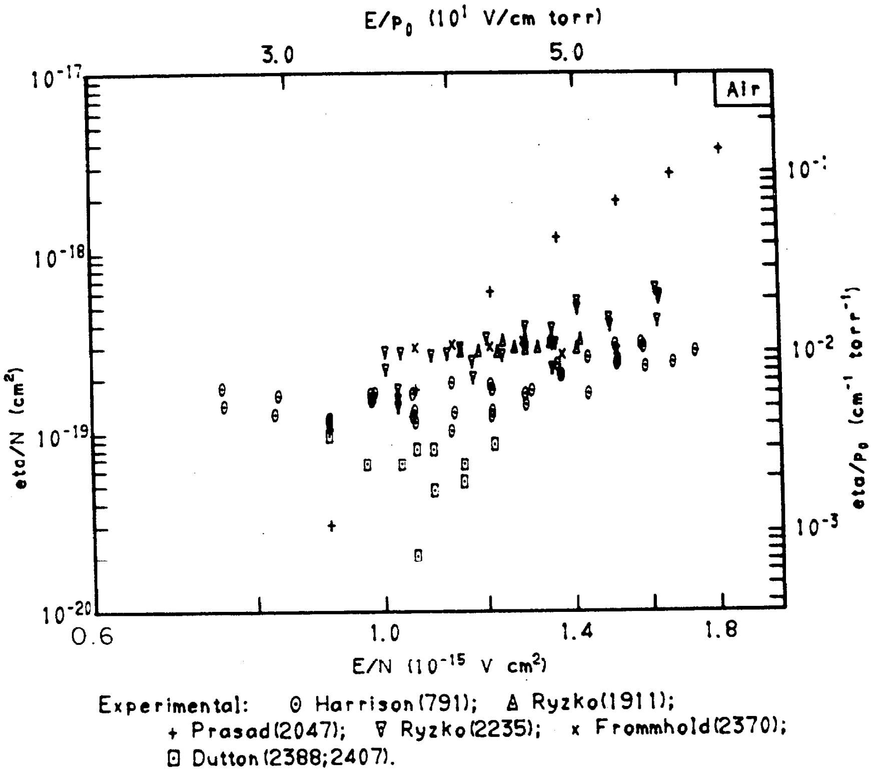


Figure 4.9. Experimental values of attachment coefficient for air for $E/N > 84 \times 10^{-17}$ V cm^2.

Table 4.1

Experimental values of η/N^2 for oxygen for $E/N < 30 \times 10^{-17}$ Vcm^2

E/N (10^{-17} Vcm^2)	N (10^{17} cm^{-3})	η/N^2 (10^{-36} cm^5)
0.2154	2.45	12.2 (a)
0.2456	2.45	11.0 (a)
0.2501	3.38	10.1 (a)
0.2801	2.45	9.8 (a)
0.2819	3.38	8.9 (a)
0.303	6.92	4.8 (d)
	8.24	5.0 (d)
	11.99	4.5 (d)
	14.49	4.2 (d)
0.307	3.38	8.1 (a)
0.309	2.45	8.6 (a)
0.364	6.92	4.5 (d)
	8.24	4.5 (d)
	11.99	4.2 (d)
	14.49	3.9 (d)
	21.74	3.2 (d)
0.485	6.92	3.9 (d)
	8.24	3.9 (d)
	11.99	3.5 (d)
	14.49	3.3 (d)
	21.74	2.99 (d)
	28.99	2.73 (d)
0.606	6.92	3.5 (d)
	8.24	3.4 (d)
	11.99	3.1 (d)
	14.49	2.83 (d)
	21.74	2.81 (d)
	28.99	2.45 (d)
0.611	4.83	4.5 (a)
0.616	2.45	4.5 (a)
0.621	3.38	4.1 (a)
0.909	6.92	2.54 (d)
	8.24	2.65 (d)
	11.99	2.38 (d)
	14.49	2.28 (d)
	21.74	2.16 (d)
	28.99	2.10 (d)
	43.5	2.16 (d)
	72.5	1.67 (d)
0.910	4.83	3.0 (a)
0.920	3.38	2.78 (a)
0.925	2.45	3.0 (a)
1.212	3.30	2.21 (b)
	4.95	2.02 (b)
	4.95	2.49 (b)
	5.77	1.65 (b)
	6.92	2.01 (d)
	8.24	2.14 (d)
	9.80	1.89 (d)
	11.99	1.87 (d)
	14.49	1.80 (d)
	21.74	1.79 (d)
	28.99	1.73 (d)
	43.5	1.61 (d)
	72.5	1.55 (d)
1.224	4.83	2.28 (a)
1.237	2.45	2.20 (a)
1.250	3.38	2.13 (a)
1.515	6.92	1.62 (d)
	8.24	1.72 (d)
	9.80	1.64 (d)
	11.99	1.59 (d)
	14.49	1.61 (d)
	21.74	1.47 (d)
	28.99	1.45 (d)
	43.5	1.47 (d)
	72.5	1.26 (d)
	144.9	1.00 (d)
1.516	4.95	1.56 (b)
	4.95	2.02 (b)
	6.60	1.65 (b)
	6.60	1.83 (b)
	11.0	1.74 (b)
	13.6	1.75 (b)
1.523	8.05	1.70 (a)
1.534	3.38	1.75 (a)
1.546	2.45	1.80 (a)
	4.83	1.78 (a)
1.694	10.62	0.64 (e)
1.819	3.30	1.67 (b)
	4.95	1.29 (b)
	4.95	1.74 (b)
	5.77	1.65 (b)
	6.60	1.38 (b)
	6.60	1.47 (b)
	6.92	1.40 (d)
	8.24	1.43 (d)
	9.80	1.39 (d)
	11.0	1.46 (b)
	11.99	1.34 (d)
	13.6	1.47 (b)
	14.49	1.40 (d)
	21.74	1.30 (d)
	28.99	1.24 (d)
	43.5	1.26 (d)
	72.5	1.13 (d)
	144.9	0.92 (d)
1.830	3.38	1.45 (a)
1.834	4.83	1.49 (a)
1.856	2.45	1.47 (a)
2.122	21.74	1.15 (d)
	72.5	0.97 (d)
	144.9	0.79 (d)
2.145	3.38	1.24 (a)
2.154	2.45	1.27 (a)
2.163	4.83	1.26 (a)
2.314	14.2	1.18 (a)

Table 4.1 (continued)

Experimental values of η/N^2 for oxygen for $E/N < 30 \times 10^{-17}$ Vcm^2

E/N (10^{-17}Vcm^2)	N (10^{17}cm^{-3})	η/N^2 (10^{-36}cm^5)
	3.30	1.09 (b)
	4.91	1.04 (d)
	4.95	1.01 (b)
	4.95	1.29 (b)
	5.77	1.11 (b)
	6.60	0.93 (b)
	6.60	1.11 (b)
	6.92	1.01 (d)
	8.24	1.07 (d)
2.425	9.80	1.05 (d)
	11.0	1.12 (b)
	11.99	1.08 (d)
	13.6	1.10 (b)
	14.49	1.03 (d)
	21.74	0.98 (d)
	28.99	0.99 (d)
	43.5	1.01 (d)
	72.5	0.88 (d)
	144.9	0.75 (d)
2.451	4.83	1.10 (a)
2.456	2.45	1.14 (a)
2.459	3.38	1.09 (a)
2.728	72.5	0.81 (d)
	144.9	0.71 (d)
2.731	4.83	0.95 (a)
2.738	2.45	1.02 (a)
2.771	3.38	0.95 (a)
3.02	8.05	0.87 (a)
	14.2	0.83 (a)
	3.30	0.74 (b)
	4.91	0.79 (d)
	4.95	0.65 (b)
	4.95	1.01 (b)
	5.77	0.92 (b)
	6.60	0.68 (b)
	6.60	0.83 (b)
	6.92	0.79 (d)
	8.24	0.85 (d)
3.03	9.80	0.84 (d)
	11.0	0.80 (b)
	11.99	0.86 (d)
	13.6	0.83 (b)
	14.49	0.86 (d)
	21.74	0.80 (d)
	28.99	0.78 (d)
	43.5	0.83 (d)
	72.5	0.75 (d)
	144.9	0.65 (d)
3.05	3.38	0.82 (a)
3.06	4.83	0.85 (a)
3.14	10.62	0.44 (e)
3.21	9.98	0.37 (c)
3.38	10.58	0.48 (e)
	6.60	0.64 (b)
3.64	11.0	0.60 (b)
	13.6	0.56 (b)
3.73	10.62	0.47 (e)

E/N (10^{-17}Vcm^2)	N (10^{17}cm^{-3})	η/N^2 (10^{-36}cm^5)
	4.91	0.53 (d)
	6.92	0.53 (d)
	8.24	0.55 (d)
	9.80	0.55 (d)
4.24	11.99	0.55 (d)
	14.49	0.48 (d)
	21.74	0.54 (d)
	28.99	0.52 (d)
	43.5	0.54 (d)
	72.5	0.51 (d)
4.49	7.79	0.57 (e)
	4.95	0.47 (b)
	4.95	0.53 (b)
	5.77	0.50 (b)
	6.60	0.49 (b)
4.55	10.44	0.34 (e)
	10.44	0.37 (e)
	11.0	0.42 (b)
	13.6	0.47 (b)
4.56	4.83	0.53 (a)
4.57	3.38	0.48 (a)
4.68	14.2	0.54 (a)
4.72	10.80	0.33 (e)
	11.12	0.37 (e)
4.75	17.4	0.55 (a)
5.34	10.66	0.32 (e)
	4.91	0.37 (d)
	6.92	0.37 (d)
	8.24	0.39 (d)
	9.80	0.38 (d)
	11.99	0.38 (d)
	14.49	0.38 (d)
5.45	21.74	0.38 (d)
	28.99	0.36 (d)
	43.5	0.39 (d)
	72.5	0.36 (d)
	144.9	0.33 (d)
	289.9	0.293 (d)
5.97	5.21	0.39 (c)
6.06	6.60	0.32 (c)
6.08	8.05	0.41 (a)
6.14	3.38	0.275 (a)
6.16	10.73	0.253 (e)
	10.76	0.297 (e)
6.50	17.84	0.176 (e)
	6.92	0.267 (d)
	8.24	0.279 (d)
	11.99	0.267 (d)
	14.49	0.269 (d)
6.67	21.74	0.267 (d)
	28.99	0.262 (d)
	43.5	0.271 (d)
	72.5	0.280 (d)
	144.9	0.241 (d)
	289.9	0.252 (d)

Table 4.1 (continued)

Experimental values of η/N^2 for oxygen for $E/N < 30 \times 10^{-17} Vcm^2$

E/N ($10^{-17} Vcm^2$)	N ($10^{17} cm^{-3}$)	η/N^2 ($10^{-36} cm^5$)
6.81	10.62	0.263 (e)
6.97	6.92	0.259 (d)
7.06	14.34	0.181 (e)
7.27	6.92	0.246 (d)
	8.24	0.254 (d)
7.58	6.92	0.241 (d)
7.61	4.83	0.230 (a)
7.77	11.43	0.269 (e)
7.88	8.24	0.246 (d)
	11.99	0.230 (d)
	14.49	0.228 (d)
	21.74	0.216 (d)
	28.99	0.207 (d)
	43.5	0.209 (d)
	72.5	0.196 (d)
	144.9	0.169 (d)
	289.9	0.190 (d)
8.42	11.33	0.232 (e)
8.49	6.92	0.259 (d)
	8.24	0.272 (d)
	11.99	0.233 (d)
	14.49	0.221 (d)
	21.74	0.207 (d)
	28.99	0.193 (d)
	43.5	0.184 (d)
	144.9	0.150 (d)
8.50	7.79	0.39 (e)
9.09	6.92	0.31 (d)
	8.24	0.31 (d)
	11.99	0.245 (d)
	14.49	0.228 (d)
	21.74	0.207 (d)
	43.5	0.172 (d)
	72.5	0.159 (d)
	289.9	0.152 (d)
9.12	10.97	0.265 (e)
9.32	10.66	0.238 (e)
9.35	3.38	0.33 (a)
9.40	28.99	0.193 (d)
9.70	21.74	0.216 (d)
	43.5	0.163 (d)
	72.5	0.146 (d)
	289.9	1.24 (d)
9.92	5.42	0.47 (e)
10.00	28.99	0.197 (d)
10.19	2.45	1.02 (a)
10.31	14.49	0.290 (d)
	43.5	0.163 (d)
	72.5	0.139 (d)
10.75	8.05	0.45 (a)
10.90	10.58	0.35 (e)
10.91	6.92	0.55 (d)
	8.24	0.49 (d)
	11.99	0.38 (d)
	21.74	0.271 (d)
	28.99	0.214 (d)
	43.5	0.168 (d)
	72.5	0.138 (d)
	144.9	0.115 (d)
	289.9	0.104 (d)
10.93	14.2	0.28 (a)
11.52	43.5	0.182 (d)
	72.5	0.135 (d)
	144.9	0.109 (d)
11.62	2.45	2.20 (a)
11.89	10.83	0.45 (e)
12.01	3.38	2.01 (a)
12.12	144.9	0.104 (d)
	289.9	0.092 (d)
12.19	8.05	0.89 (a)
12.73	6.92	0.88 (d)
	8.24	0.81 (d)
	14.49	0.47 (d)
	21.74	0.38 (d)
	28.99	0.286 (d)
	43.5	0.230 (d)
	72.5	0.146 (d)
	289.9	0.088 (d)
13.10	2.45	3.5 (a)
13.31	14.34	0.40 (e)
13.83	4.83	2.13 (a)
13.94	289.9	0.082 (d)
14.10	10.34	0.67 (e)
14.54	289.9	0.080 (d)
14.88	8.05	1.85 (a)
15.08	3.38	3.9 (a)
15.15	6.92	1.53 (d)
	8.24	1.31 (d)
	14.49	0.77 (d)
	21.74	0.58 (d)
	28.99	0.44 (d)
	43.5	0.31 (d)
	72.5	0.196 (d)
	144.9	0.117 (d)
	289.9	0.079 (d)
15.82	5.42	1.67 (e)
16.00	2.45	6.0 (a)
16.10	10.34	0.0108 (e)
16.50	4.83	3.4 (a)
17.66	14.34	0.0092 (e)
	10.87	0.0126 (e)
	10.87	0.0140 (e)
18.07	8.05	2.24 (a)

Table 4.1 (continued)

Experimental values of η/N^2 for oxygen for $E/N < 30 \times 10^{-17} Vcm^2$

E/N ($10^{-17} Vcm^2$)	N ($10^{17} cm^{-3}$)	η/N^2 ($10^{-36} cm^5$)	E/N ($10^{-17} Vcm^2$)	N ($10^{17} cm^{-3}$)	η/N^2 ($10^{-36} cm^5$)
	6.92	2.25 (d)	22.63	11.12	0.0200 (e)
	8.24	1.91 (d)	23.09	4.83	4.7 (a)
	14.49	1.11 (d)		6.92	3.2 (d)
	21.74	0.78 (d)		8.24	2.75 (d)
18.19	28.99	0.60 (d)		14.49	1.57 (d)
	43.5	0.41 (d)		21.74	1.00 (d)
	72.5	0.251 (d)	24.25	28.99	0.77 (d)
	144.9	0.130 (d)		72.5	0.31 (d)
	289.9	0.085 (d)		144.9	0.161 (d)
				289.9	0.097 (d)
18.36	17.84	0.0090 (e)			
19.10	2.45	7.9 (a)	24.31	3.38	7.2 (a)
19.49	7.79	0.0216 (e)	25.71	17.84	0.0141 (e)
19.80	4.83	4.3 (a)	25.88	4.83	5.2 (a)
20.85	3.38	6.5 (a)	27.09	3.38	7.5 (a)
21.07	11.08	0.0165 (e)			
				6.92	3.4 (d)
	6.92	2.76 (d)		14.49	1.72 (d)
	8.24	2.42 (d)		21.74	1.12 (d)
	14.49	1.37 (d)	27.28	28.99	0.87 (d)
21.22	21.74	0.92 (d)		43.5	0.63 (d)
	28.99	0.71 (d)		72.5	0.36 (d)
	43.5	0.49 (d)		144.9	0.186 (d)
	72.5	0.30 (d)		289.9	0.099 (d)
	144.9	0.153 (d)	28.33	10.73	0.0262 (e)

Experimental:
(a) Chanin, et al., Phys. Rev. 128, 219 (1962).
(b) Rees, Austr. J. Phys. 18, 41 (1965).
(c) Chatterton, et al., J. Electron. Control 11, 425 (1961).
(d) Grunberg, Z. Naturforsch. 24a, 1039 (1969).
(e) Doehring, Z. Naturforsch. 7a, 253 (1952).

Table 4.2

Experimental values of the thermal three-body attachment rate coefficient for oxygen at various temperatures

T (°K)	a_3 (10^{30}cm^6/sec)	T (°K)	a_3 (10^{30}cm^6/sec)	T (°K)	a_3 (10^{30}cm^6/sec)
77	<1 (a)		2.8 (a)	370	3.1 (a)
113	0.72 (b)		2.0 (c)	530	2.8 (c)
195	2 (a)		3.0 (d)		
200	1.5 (b)	300	2.3 (e)		
			2.4 (f)		
			2.12 (g)		
			2.2 (h)		

Experimental:
(a) Chanin, et al., Phys. Rev. 128, 219 (1962).
(b) Truby, Phys. Rev. A 6, 671 (1972).
(c) Pack and Phelps, J. Chem. Phys. 44, 1870 (1966).
(d) Brodski, et al., Sov. Phys. Tech. Phys. 11, 498 (1966).
(e) Hackam, et al., Proc. Phys. Soc. (London) 86, 123 (1965).
(f) Lennon, et al., Proc. Phys. Soc. (London) 78, 1543 (1961).
(g) Hirsh, et al., Phys. Rev. 178, 175 (1969).
(h) Warman, et al., Chem. Phys. Lett. 12, 211 (1971).

Table 4.3

Experimental values of η/N for oxygen for E/N > 30 × 10^{-17}Vcm^2

E/N (10^{-17}Vcm^2)	η/N (10^{-18}cm^2)	E/N (10^{-17}Vcm^2)	η/N (10^{-18}cm^2)	E/N (10^{-17}Vcm^2)	η/N (10^{-18}cm^2)
30.3	2.5 (a)	42.3	2.5 (c)	53.0	2.5 (a)
	1.28 (b)	42.4	1.39 (b)	54.5	1.06 (b)
33.3	0.23 (b)	45.5	2.6 (a)	60.6	2.4 (c)
36.4	1.36 (b)		0.71 (b)		2.2 (a)
37.9	2.6 (a)	48.5	2.5 (c)	72.1	1.9 (c)
39.4	1.46 (b)		1.42 (b)		

Experimental:
(a) Huxley, et al., Austr. J. Phys. 12, 303 (1959).
(b) Grunberg, Z. Naturforsch. 24a, 1039 (1969).
(c) Chatterton, et al., J. Electron. Control 11, 425 (1961).

Table 4.4

Experimental values of η/N^2 for nitric oxide

E/N (10^{-17}Vcm^2)	N (10^{-18}cm^{-3})	η/N^2 (10^{-37}cm^5)	E/N (10^{-17}Vcm^2)	N (10^{-18}cm^{-3})	η/N^2 (10^{-37}cm^5)
0.927	5.25	10.1	4.98	5.25	3.8
1.421	5.25	8.4	5.68	3.9	3.6
1.963	5.25	6.6	8.09	3.9	2.5
2.160	3.45	5.7	8.58	3.45	2.06
2.738	5.25	5.2	9.87	3.9	2.24
2.786	3.45	6.0	10.47	2.65	1.90
3.06	5.25	5.9	11.65	2.65	1.36
3.82	5.25	4.3	13.15	2.65	1.63
4.28	3.45	3.4	14.58	2.65	1.63
4.44	2.2	3.8	15.50	2.2	1.08
			17.43	2.2	0.70

Experimental:
All data taken from Parkes, et al., J. Chem. Soc. Faraday Trans. II 68, 600 (1972).

3.5. Detachment Coefficient

In section 3.4 a number of processes are listed by which, in an electronegative gas, negative ions can be produced in an electron swarm by collisions between electrons and the gas atoms or molecules. These processes of electron attachment are all reversible giving rise to corresponding processes of electron detachment in which electrons are removed from negative ions by providing the energy difference required. In swarm conditions, the only processes of detachment that are significant are those resulting from collisions of the negative ions with neutral gas particles and these processes can be represented by the equations

$$A^- + B + \text{k.e.} \rightarrow A + B + e,$$

$$A^- + B \rightarrow AB + e,$$

which are the reverse of three-body and dissociative attachment, respectively.

Of the gases considered in this review, values of the detachment rate coefficients and of the detachment coefficient have been obtained only (i) for oxygen negative ions, either in oxygen or in mixtures of oxygen with other gases, particularly air and (ii) for nitric oxide negative ions in mixtures of nitric oxide and oxygen. The data obtained are discussed in the next two subsections.

3.5.a. Detachment Coefficients—Oxygen

At low values of E/N for which ionization is negligible, the continuity equations for an electron swarm moving in an electronegative gas in which attachment and detachment are occurring may, neglecting diffusion, be written

$$\frac{\partial n}{\partial t} + W\frac{\partial n}{\partial x} = -an + dN_-$$

$$\frac{\partial n}{\partial t} + W_-\frac{\partial N}{\partial x} = an - dN_-$$

where n and N_- are the electron and negative ion number densities and W and W_- are the electron and negative ion drift velocities, respectively.

These equations were used by Pack and Phelps [1662] as the basis of the analysis of the wave-form of the current observed to result from the liberation of a pulse of electrons from the cathode of a drift tube. The value of E/N in the drift tube was maintained at a value sufficiently low ($\sim 3\times10^{-17}$ V cm^2) for the negative ions to remain in thermal equilibrium with the gas molecules. In this way, values of the thermal detachment rate coefficient were obtained over the range $375 < T < 573$ K and for values of N from about 10^{17} to 10^{19} cm^{-3}. These values are shown as a graph of d, T in figure 5.1 and given in table 5.1.

Detachment rate coefficients have also been determined for several mixtures of oxygen with small amounts of other gases. These were obtained using flowing afterglow techniques [3042] and from measurements in drift tubes of mass identified ion currents [5700] and of the time-resolved electron component of pulses generated by photoelectric emission from the cathode [3352]. The values obtained from the drift tube measurements for the detachment rate coefficients for the associative detachment reactions

$$O^- + H_2 \rightarrow H_2O + e,$$

$$O^- + CO \rightarrow CO_2 + e,$$

and $$O^- + NO \rightarrow NO_2 + e,$$

are shown as functions of E/N in figures 5.2, 5.3, and 5.4.

Using Wannier's expression (G. Wannier, Phys. Rev. **83,** 281, 1951; **89,** 795, 1952) for the mean energy of the negative ions, the range of values of mean energy corresponding to the range of experimental values of E/N was found to be about 0.04 to 0.7 eV. The results are thus in accord with the results of the afterglow studies [3042] which gave values for the associative detachment rates at thermal energy (0.039 eV at 300 K) of 7.6×10^{-10} cm^3 s^{-1} for H_2, 5.4×10^{-10} cm^3 s^{-1} for CO and 3.2×10^{-10} cm^3 s^{-1} for NO. (These values are updated values given graphically in [3352].)

Both drift tube and flowing afterglow studies show that the associative detachment rate for O^- in nitrogen is very low, an estimate $\sim 10^{-19}$ cm^3 s^{-1} being given in [3352].

Microwave measurements on a decaying afterglow in relative large admixtures (10 to 20 percent) of oxygen in nitrogen at a nitrogen pressure of about 9 Torr were made by Hackam and Lennon [1633]. The variation of decay rate with the oxygen content of the mixture was interpreted to give a value of $d = 8.4\times10^{-15}$ cm^3 s^{-1} at $T = 296$ K for the detachment rate coefficient of oxygen negative ions in collision with nitrogen molecules.

At higher values of E/N, when ionization becomes a significant process, attempts have been made to obtain values of the detachment coefficient both from measurements on pulsed [1444, 2370] and steady-state [2462, 2555, 4948] electron swarms. The analysis of the experimental data has, however, proved difficult, because of the large number of significant processes occurring and their relative magnitudes. The solution of the appropriate continuity equations in the steady state is given by equation (16). (See sec. 3.7.c.)

Analysis of the steady-state data has been carried out using this equation and various simplifying assumptions (e.g., that secondary ionization and ion conversion are negligible). With this assumption it was found that the detachment coefficient δ for $100\times10^{-17} < E/N < 140\times10^{-17}$ V cm^2 is small compared with the attachment coefficient η, values of δ/N in the range from zero to about 3×10^{-19} cm^2 having been obtained, depending on the conditions. Unfortunately, when

δ/η is small there is no significant difference in the best fit to the experimental data for a wide range of combinations of the coefficients which include the possibility of $\delta=0$. In a recent reanalysis [4947] of the steady-state data, it has been suggested that inclusion of ion conversion would lead to values of δ compatible with the much higher values ($\delta/N \sim 1.5 \times 10^{-17}$ cm^2) found by analysis [2370] of the pulse data. It should be pointed out, however, that the inclusion of ion conversion in the steady-state analysis enables an even wider range of combinations of coefficients to be used to give agreement with the experimental data and the possibility of $\delta=0$ is still not excluded.

That δ/p is finite but small in this region of E/N was definitely established by further experiments [2994, 4920, 4949] on the steady-state spatial growth of current resulting from an initial negative-ion current. The values obtained for δ/N were $\sim 3 \times 10^{-19}$ cm^2 at $p=20$ Torr, decreasing as the pressure increased to 60 Torr, but no detailed agreement has yet been obtained between different sets of data obtained using this procedure. Moreover none of the analyses used included either the effect of ion conversion reactions or of the presence of electrons mixed with the initial negative ion current. Comparison of these experiments is further complicated by the fact that the proportion of the ion species O^-, O_2^-, and O_3^- in the initial negative-ion current depends on the conditions in the sources which were different. To obtain definitive results on detachment coefficients in oxygen for $E/N > 99 \times 10^{-17}$ V cm^2 requires further work, preferably in a system in which the ion species can be identified.

3.5.b. Detachment Coefficient—Nitric Oxide

Parkes and Sugden [4943] obtained a value of $(5 \pm 1) \times 10^{-12}$ cm^3 s^{-1} for the detachment coefficient of near-thermal NO^- ions from an analysis of experiments in which the mass identified ion current at the end of a drift tube was measured as a function of oxygen concentration in NO/O mixtures at $E/N=3.1 \times 10^{-17}$ V cm^2.

3.5.c. Detachment Coefficient—Air

There are no values for the detachment coefficient at low values of E/N in air.

At values of $E/N > 85 \times 10^{-17}$ V cm^2 where ionization becomes significant, measurements have been made of both the spatial growth of an electron swarm in the steady state [791, 2047, 2407, 2919] and of the temporal growth under impulse conditions [2235, 2370, 4947] for $85 \times 10^{-17} < E/N < 140 \times 10^{-17}$ V cm^2. The same difficulties of analysis arise as in the case of oxygen so that the values of the detachment coefficient are not well defined. The values obtained are very dependent on the assumptions made in the analysis, and even for a given set of assumptions agreement between theory and experiment can be obtained for a wide range of combinations of values of the coefficients involved. Thus values of δ/N ranging from zero to 1.5×10^{-17} cm^2 have been shown [791, 2047, 2407, 4947] to be compatible with the steady-state experimental results, while three sets of impulse data [2235, 2370, 4947] have been analyzed to give values of δ/N in the upper end of this range, but without any indication of the range of values of the coefficients which could be used to fit the experimental data. So far, no experiments on the development of an initial negative-ion current such as those carried out in oxygen have been reported for air.

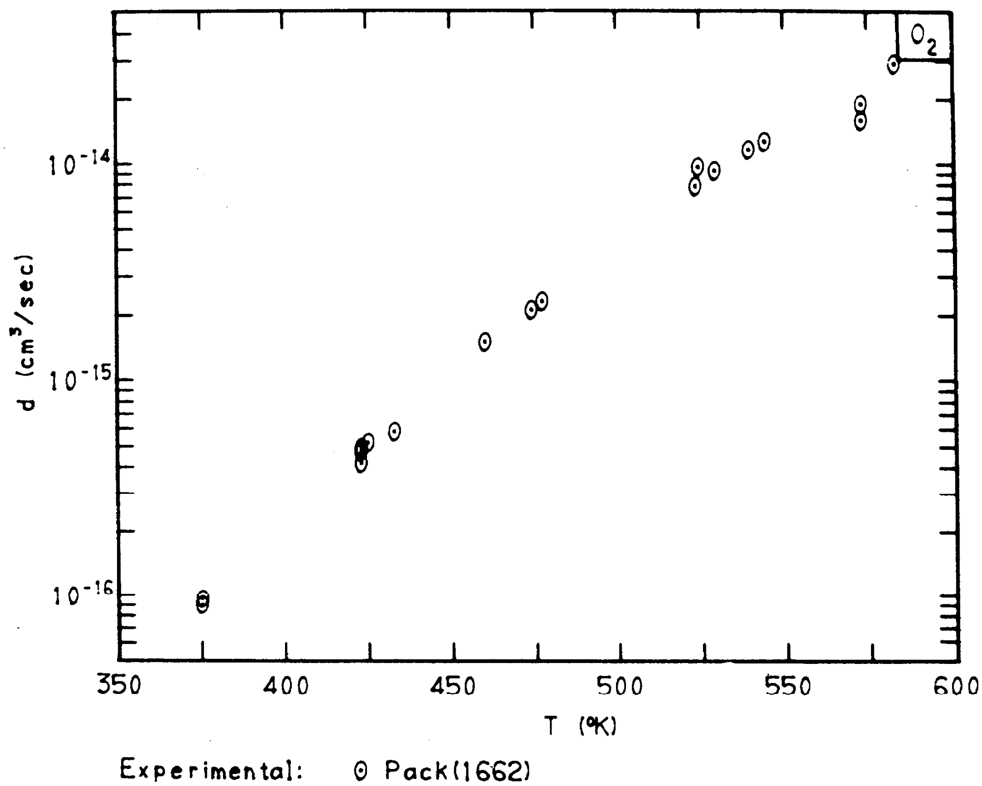


FIGURE 5.1. Thermal detachment rate coefficients for oxygen ions in oxygen as a function of temperature.

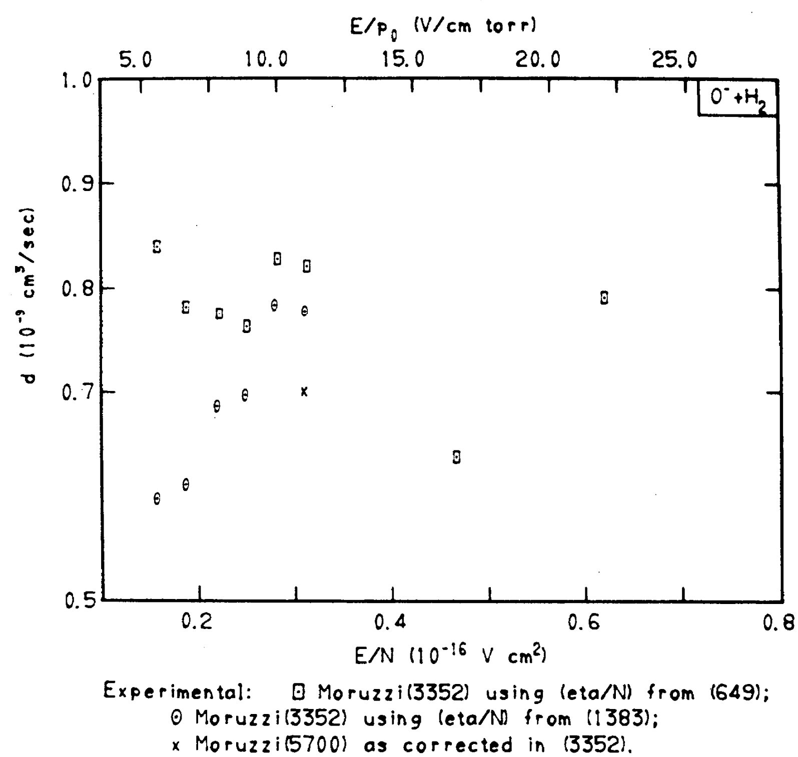
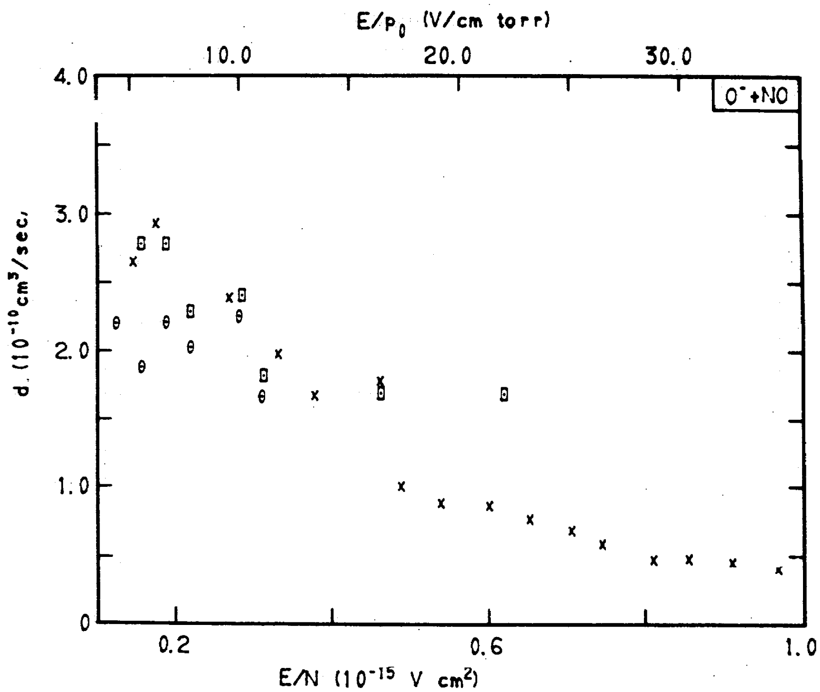
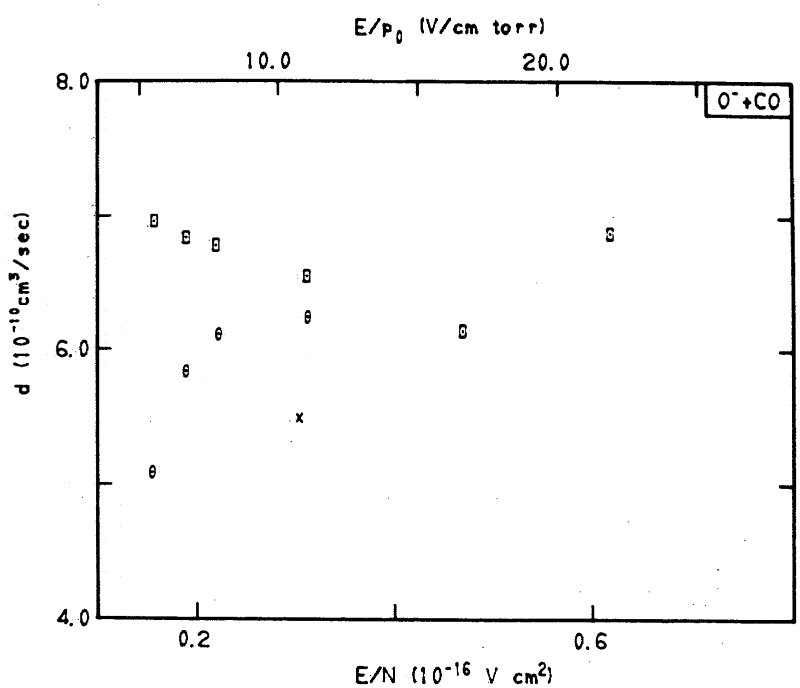


FIGURE 5.2. Associative detachment rate coefficient for the reaction $O^- + H_2 \rightarrow H_2O + e$ as a function of E/N.



Experimental: ⊡ Moruzzi(3352) using (eta/N) from (649); ⊙ Moruzzi(3352) using (eta/N) from (1383); x Moruzzi(5700) as corrected in (3352).

FIGURE 5.3. Associative detachment rate coefficient for the reaction $O^- + NO \rightarrow NO_2 + e$ as a function of E/N.



Experimental: ⊡ Moruzzi(3352) using (eta/N) from (649); ⊙ Moruzzi(3352) using (eta/N) from (1383); x Moruzzi(5700) as corrected in (3352).

FIGURE 5.4. Associative detachment rate coefficients for the reaction $O^- + CO \rightarrow CO_2 + e$ as a function of E/N.

Table 5.1

Thermal detachment coefficients for oxygen

Temperature (°K)	d ($10^{-15}cm^3$/sec)	Temperature (°K)	d ($10^{-15}cm^3$/sec)	Temperature (°K)	d ($10^{-15}cm^3$/sec)
375.	{0.090	433.	0.58	529.	9.3
	{0.096	460.	1.5	539.	11.7
423.	{0.42	474.	2.1	544.	12.7
	{0.47	477.	2.3	573.	{16.
	{0.49	523.	7.9		{19.
425.	0.52	524.	9.7	583.	29.

Experimental:
All data taken from Pack, et al., J. Chem. Phys. 44, 1870 (1966).

3.6. Excitation Coefficient

Some of the energy gained from the field by the electrons in an electron swarm is given up in inelastic collisions which lead to the excitation of the gas atoms or molecules. The number of excitations produced by n electrons moving a distance, dx, in the field direction is $n \epsilon\, dx$, where ϵ is the excitation coefficient.

If the excited states produce decay with the emission of radiation, measurements of the light emitted from the swarm, as a function of the distance from the cathode of a uniform field electrode system, may be used to determine ϵ_r, the excitation coefficient to radiative states. The light emitted by any given excited level at the currents ($i < 10^{-7}$ A) existing in electron swarms is of very low intensity. Thus, most measurements have been concerned with the determination of the total radiation emitted which leads to an average value of ϵ_r for all the radiating states involved. In some experiments [1761, 2229] however, the value of ϵ_r for excitation to states giving rise to particular radiations has been obtained by measuring the light emitted from the whole of a discharge in a narrow range of wavelengths.

In molecular gases, excitation may occur to repulsive states which leads to dissociation. Measurement of the number of dissociations produced by a given current can then be used to evaluate ϵ_d, the excitation coefficient to dissociating states, which is often termed, simply, the dissociation coefficient.

Of the gases with which this data survey is concerned, excitation coefficients have been obtained experimentally for H_2, N_2, O_2 and CO_2 and have been calculated theoretically for He and Ne. The values obtained are given in the succeeding subsections.

3.6.a. Excitation Coefficient—Helium

When an electron swarm moves through helium both metastable and radiating states are excited. There are no published experimental values of excitation coefficients for helium, but there have been a number [336, 3897, 4057, 5701, 4909] of theoretical calculations both of the total excitation coefficient and of the partial excitation coefficients to metastable states and to radiating states. The values obtained are shown in figures 6.1 and 6.2 and given in table 6.1 (epsilon in the figures ≡ ϵ in the text).

All these values of ϵ are based on the published data [119, 318, 2010] (see also H. S. W. Massey and E. H. S. Burhop, *Electronic and Ionic Impact Phenomena*, Clarendon Press, Oxford, 1969, 2nd Ed., Vol. 1) on the cross sections involved. In [336, 4057, 5701, and 4909] analytical methods were used, based in one case [336] on a previously published [2010] energy distribution function, and in the others on distributions obtained for the purpose. In [3897] a Monte Carlo method was used.

3.6.b. Excitation Coefficient—Neon

The only available published information on excitation coefficients for electron swarms in neon are the values of the total excitation coefficient calculated by Hughes [4909] and the approximate values for the excitation coefficient to the $^3P_2$ level calculated in [2501] using expressions given in [3552]. These values are shown in figure 6.3, the values for the excitation coefficient also being tabulated in table 6.2.

3.6.c. Excitation Coefficient—Hydrogen

The radiation produced by an electron swarm moving through hydrogen lies mostly in the far ultraviolet (1000 to 1200 Å), resulting from the excitation of the $2\,^1\Pi_u$ state. A direct measurement of the excitation coefficient was made [354] by determining, at various distances from the cathode, the far-ultraviolet radiation emitted from a small length Δx of an electron avalanche (current $i < 10^{-8}$ A) established between parallel plates. These measurements gave values both of the excitation coefficient ϵ_r, which are shown in figure 6.4, and given in table 6.3, and of the ionization coefficient α. The values of α so obtained were in good agreement with those obtained using the Townsend method (see fig. 7.5).

In other experiments, the radiation emitted by the whole discharge, either axially from an avalanche with $i \lesssim 10^{-8}$ A [921] or radially from a self-sustaining Townsend discharge with 1 μA < i < 10 μA [3722], was measured together with the value of the current flowing.

n both these experiments the emission at a constant alue of E/N was found to depend on the gas pressure ($1 < p < 100$ Torr), because of the quenching of adiation in collisions of the second kind between xcited and neutral gas molecules. When the results ere corrected for this pressure effect they gave values f ϵ_r/α. In [921], absolute values of ϵ_r/α were obtained nd converted into the values of ϵ_r/N shown in figure .4 (and given in table 6.3) by using the values of α/N iven in [1356]. In [3722], however, relative values of $_r/\alpha$ were obtained, converted to relative values of $_r/N$ using values of α/N given in [2150], and then normalized to give the values shown in figure 6.4. This normalization was carried out by adjusting the value of ϵ_r/N to agree with the absolute values of [354] and of [921] at low values of E/N.

Observations [1761] of the radiation from a self-sustained Townsend discharge, at currents up to 300 μA, using interference filters gave values of ϵ_r for the excitation of states leading to the emission of H_α and H_β radiation and these are shown in figure 6.5.

Comparison of figures 6.5 and 6.4 shows that the number of molecules excited so as to give H_α and H_β radiation is much smaller than those excited to the $2^1\Pi_u$ state.

On the other hand, the dissociation coefficient ϵ_d, which is essentially a measure of the excitation coefficient to the $^3\Sigma_u^+$ and $^3\Sigma_g^+$ states is much larger than ϵ_r for the $2^1\Pi_u$ state, as can be seen from figures 6.6 and 6.4. Figure 6.6 and table 6.4 show the values of ϵ_d obtained from measurements of the number of molecules dissociated by a radiofrequency (5 MHz) discharge [354] and by a dc discharge [4950]. A maximum value of ϵ_d/E of 6.5×10^{-2}, which is close to that given in figure 6.6 was also obtained [4951] from measurements on the dissociation in a discharge at a frequency of 3000 MHz. Fair agreement between the experimental values of ϵ_d in figure 6.6 and those calculated [4950], on the assumption of a Maxwellian energy distribution, by the method given in [2109] can be obtained, provided the cross section for excitation to the $^3\Sigma_u^+$ and $^3\Sigma_g^+$ levels is assumed to be about a factor of 2.6 times greater than the theoretical value of about 0.2 πa_0^2, obtained by a wave mechanical calculation [see 2109 and 4951].

Values of $(\epsilon_r + \epsilon_d)$ calculated [260] using cross sections obtained from numerical integration of the Boltzmann equation and comparison with swarm data are shown in figure 6.7 together with the experimental values obtained by the addition of the values of ϵ_r and ϵ_d given in figures 6.4 and 6.6.

It should be noted that the concept of a swarm coefficient ϵ/N at high values of E/N (say $> 4 \times 10^{-15}$ V cm^2 for hydrogen) is questionable, because equilibrium conditions are not established in the experiments.

3.6.d. Excitation Coefficient—Nitrogen

When an electron avalanche moves through nitrogen, ultraviolet radiation with wavelength in the range 3400 to 3800 Å, corresponding to the second positive group which involves $C\,^3\Pi_u \rightarrow B\,^3\Pi_g$ transitions, is emitted. Absolute measurements were made in [921] of the intensity of this radiation emitted axially from avalanches in which the current was $< 10^{-8}$ A. These showed that for 1 Torr $< p <$ 10 Torr the intensity was independent of pressure at a given value of E/N. At higher pressures (10–100 Torr), however, quenching of the radiation in collisions of the second kind led to a decrease in emission with increasing pressure at a given E/N. For this region, the value of ϵ_r/α was obtained from the measured coefficient $(\epsilon_r/\alpha)_m$ say, using the relationship

$$\epsilon_r/\alpha = (\epsilon_r/\alpha)_m(1 + p/p_q),$$

where p is the pressure and p_q is a constant (found to be 60 Torr for nitrogen), called the "quenching pressure." The pressure p_q is that at which one half of the excited molecules produced are destroyed by quenching. The values obtained for ϵ_r/α from this equation gave a single curve for ϵ_r/α, E/N, which was independent of pressure and in close agreement with the values obtained at low pressures. These values are shown in figure 6.8. Also shown in figure 6.8 are values of ϵ_r/α computed [921] assuming a Maxwellian energy distribution for the electrons, a maximum cross section for excitation of 0.88×10^{-16} cm^2 and an excitation potential of 11.04 eV.

The experimental values of ϵ_r/α were converted to the values of ϵ_r/N shown in figure 6.9 by using the values of α/N given in [2556]. These values of ϵ_r/N, which are tabulated in table 6.5, have recently been confirmed in other similar experiments [4993]. Also shown in figure 6.9 are values computed [218] using a self-consistent set of cross sections obtained by solving the Boltzmann equation.

3.6.e. Excitation Coefficient—Oxygen

Measurements [3268] of the intensity of radiation in the vacuum ultraviolet from electron avalanches, in which the current densities were less than 10^{-8}A/cm^2, in O_2 gave the values of ϵ_r/α shown in figure 6.10. The intensity of radiation was found to be dependent on pressure for $0.5 < p < 20$ Torr because of quenching, and the experimental results were interpreted using the equation given in section 3.6.d with the quenching pressure $p_q = 2.5$ Torr.

When the results for ϵ_r/α were published, there was doubt about the values of α/N in oxygen so that no values of ϵ_r/N were given. Reliable values of α/N have recently been obtained [4994], however, and those have here been used to convert the values of ϵ_r/α in figure 6.10 to give the values of ϵ_r/N for the range of E/N which the results overlap in figure 6.11.

3.6.f. Excitation Coefficient—Carbon Dioxide

Measurements [4993] of the vacuum ultraviolet emission produced by electron avalanches in carbon dioxide showed that at a given value of E/N, the intensity decreased with increasing pressure for $1 < p < 10$ Torr. A single curve of ϵ_r/α, E/N was obtained using the expression given in section 3.6.d and a quenching pressure of 3.6 Torr. From this curve, unspecified values of α were used to obtain the curve of ϵ_r/N, E/N shown in figure 6.12 and given in table 6.6(a).

Measurements of the increase in total pressure and of the pressure of the permanent gas products resulting from running a glow discharge in CO_2 for a given time were used [5702] to obtain the values of the dissociation coefficient in CO_2 shown in figure 6.13 and given in table 6.6(b). A dissociative rate coefficient of 7×10^{-15} cm^3 s^{-1} was obtained [5607] from measurements of the dependence of the fractional concentration of CO on flow velocity and position in a CO_2 laser for which the value of E/N on the axis was about 2.2×10^{-16} V cm^2. This value is stated [5607] to be in good agreement with that calculated using the cross section in [2553] and with the data in [5702].

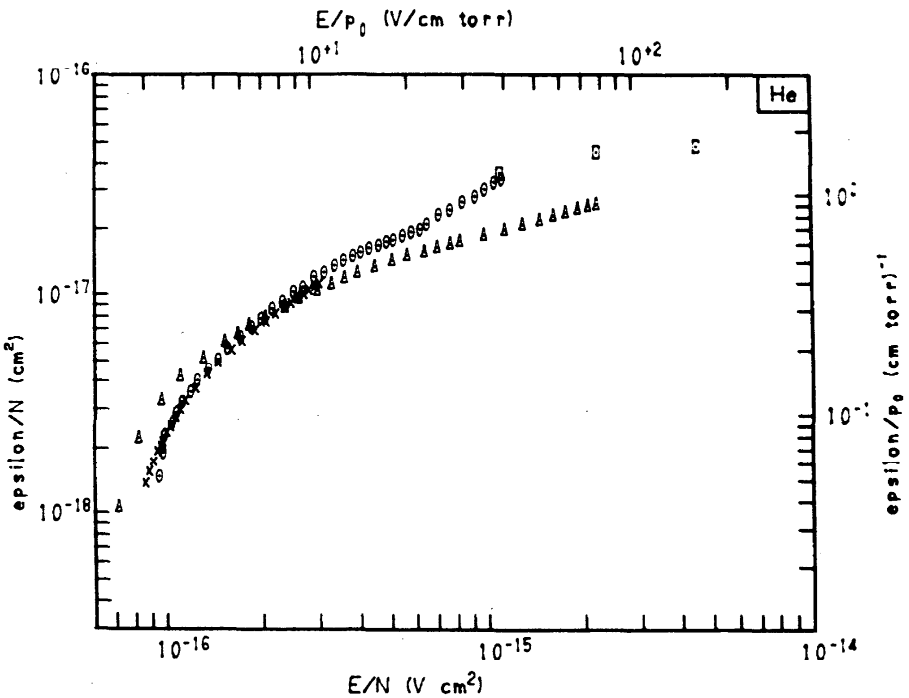


FIGURE 6.1. Theoretical values of the total excitation coefficient (to radiating and metastable states) for helium.

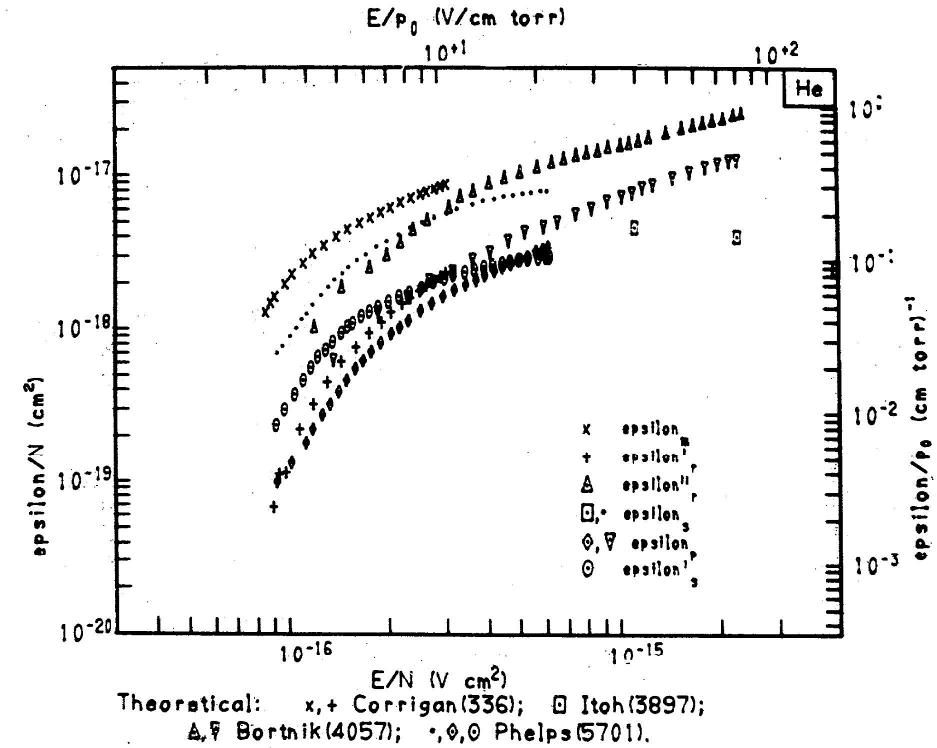


FIGURE 6.2. Theoretical values of partial excitation coefficients to various levels and groups of levels in helium. (ϵ, total excitation coefficient; ϵ_m, sum of excitation coefficients to the 2^3S, 2^1S and 2^3P levels; ϵ_r', sum of the excitation coefficients to all states except the 2^3S, 2^1S and 2^3P levels; ϵ_r'', sum of excitation coefficients to all states except the 2^3S and 2^1S levels; ϵ_p, excitation coefficient to the 2^1P level; ϵ_s, excitation to the 2^3S level; ϵ_s', excitation to the 2^1S level.)

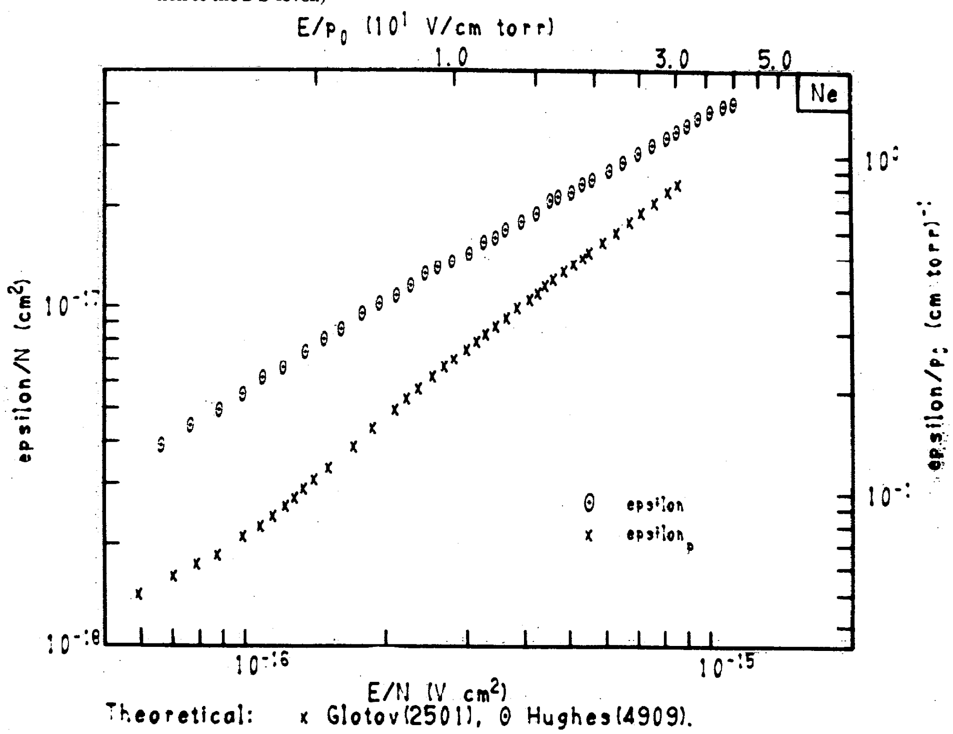


FIGURE 6.3. Theoretical values of the total excitation coefficient (ϵ) and the excitation coefficient to the $^3P_2$ level (ϵ_p) of neon. (A temperature of 0 °C was assumed for converting the value of E/p in [2501] to E/N.)

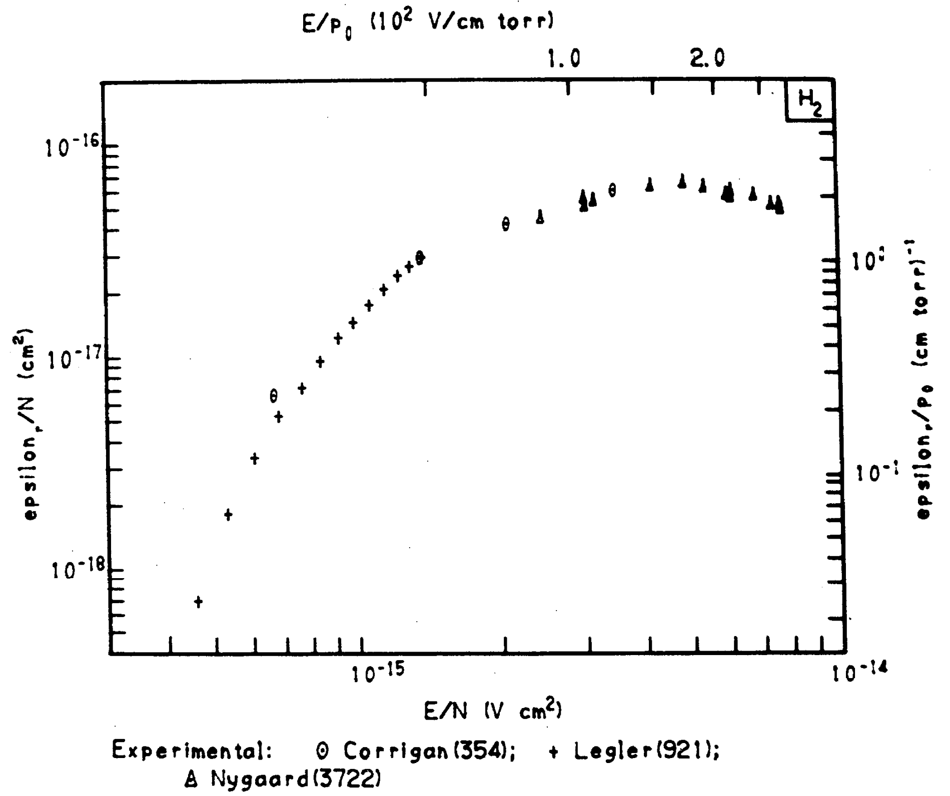


FIGURE 6.4. Experimental values of ϵ_r/N as a function of E/N for the $2^1\Pi_u$ state of hydrogen. (The temperature has been assumed to be 20 °C for the results given in [354] and [3722].)

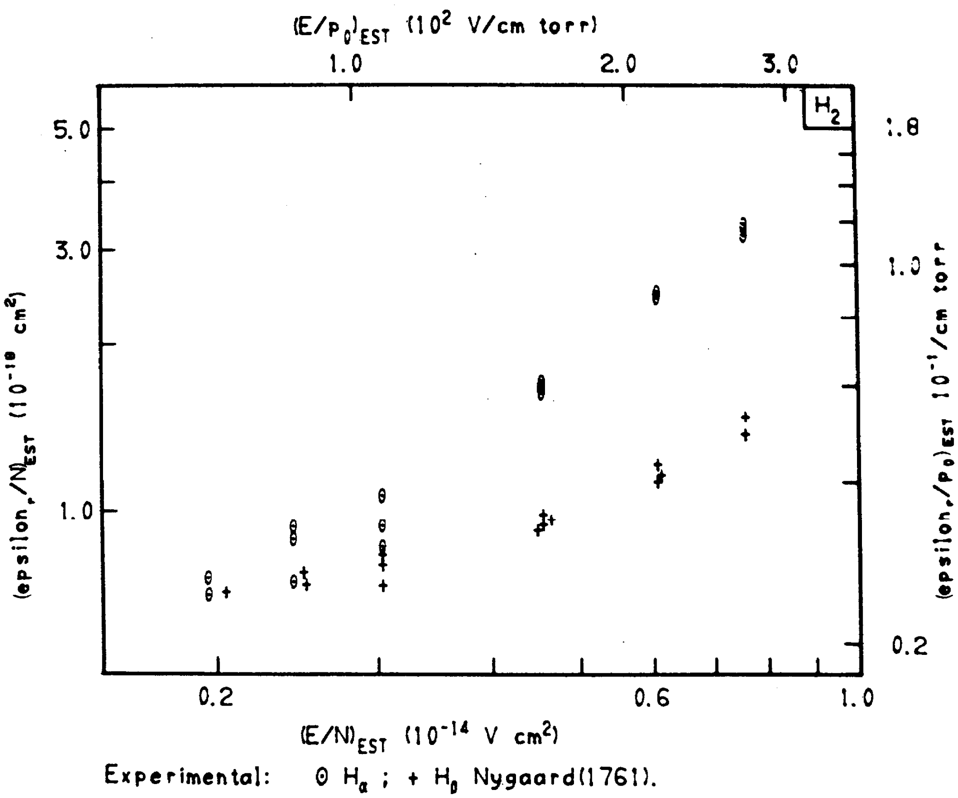
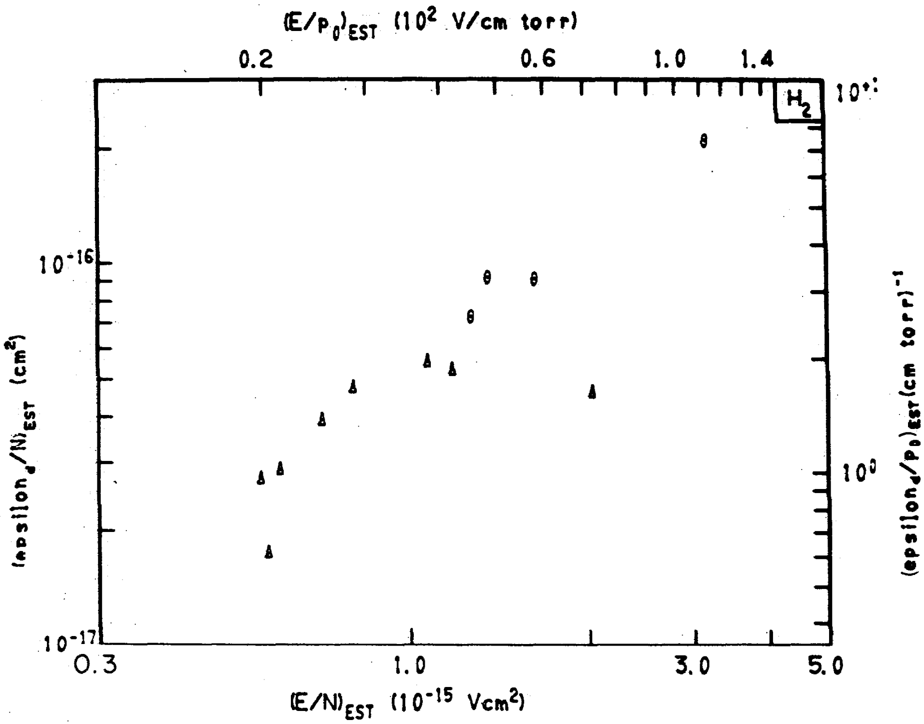
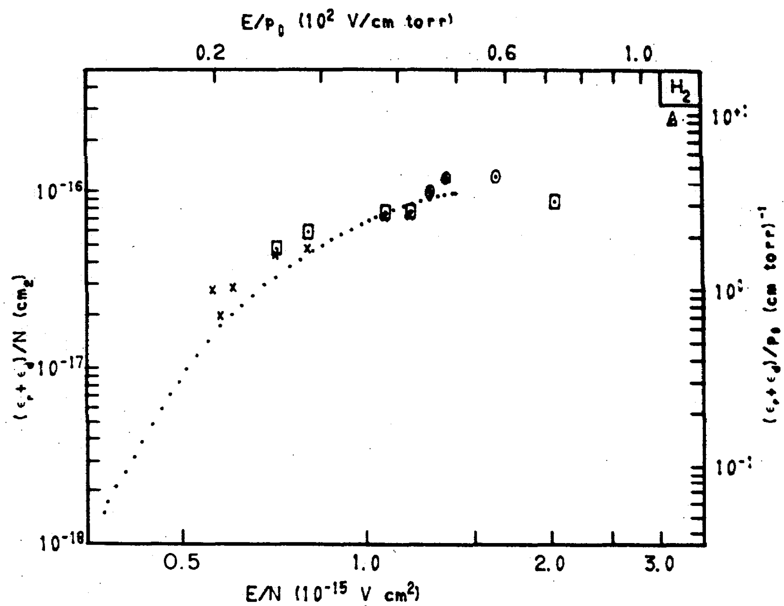


FIGURE 6.5. Experimental $(\epsilon_r/N)_{Est}$, $(E/N)_{Est}$ for excitations leading to the emission of H_α and H_β radiation. (A temperature of 20 °C was assumed.)



Experimental: ⊙ Corrigan (354); Δ Poole (4950).

FIGURE 6.6. Experimental values of the excitation coefficient leading to dissociation (dissociation coefficient) $(\epsilon_d/N)_{Est}$ as a function of $(E/N)_{Est}$ (The temperature was assumed to be 20 °C.)



Experimental: ⊙ Corrigan (354) and Corrigan (354)
+ Legler (921) and Corrigan (354)
Δ Nygaard (3722) and Corrigan (354)
⊡ Corrigan (354) and Poole (4950)
x Legler (921) and Poole (4950).
Theoretical: • Engelhardt (260).

FIGURE 6.7. Comparison of theoretical and experimental values of the total excitation coefficient $(\epsilon_r+\epsilon_d)/N$ for hydrogen.

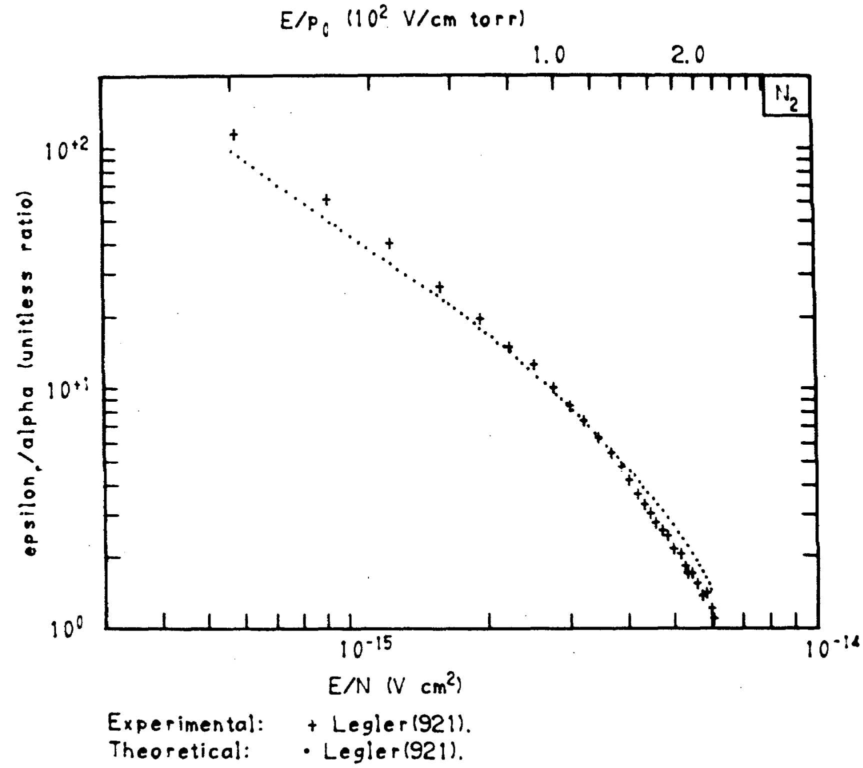


FIGURE 6.8. Comparison of experimental and theoretical values of ϵ_r/α for nitrogen.

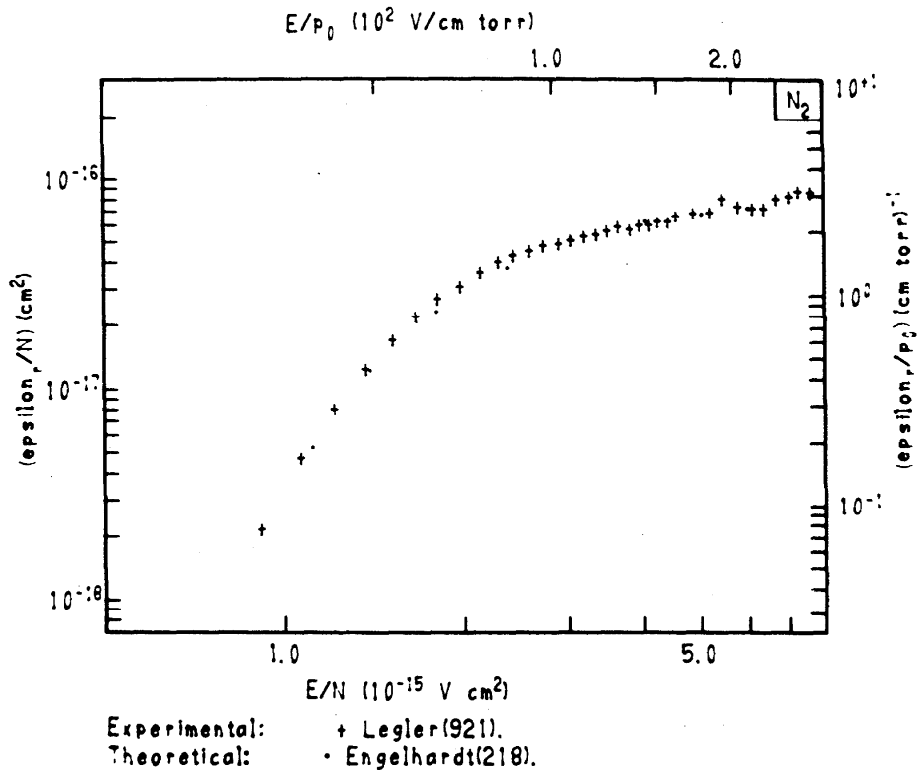


FIGURE 6.9. Comparison of experimental and theoretical values of ϵ_r/N, E/N for excitations to the $C\,^3\Pi_u$ state of nitrogen.

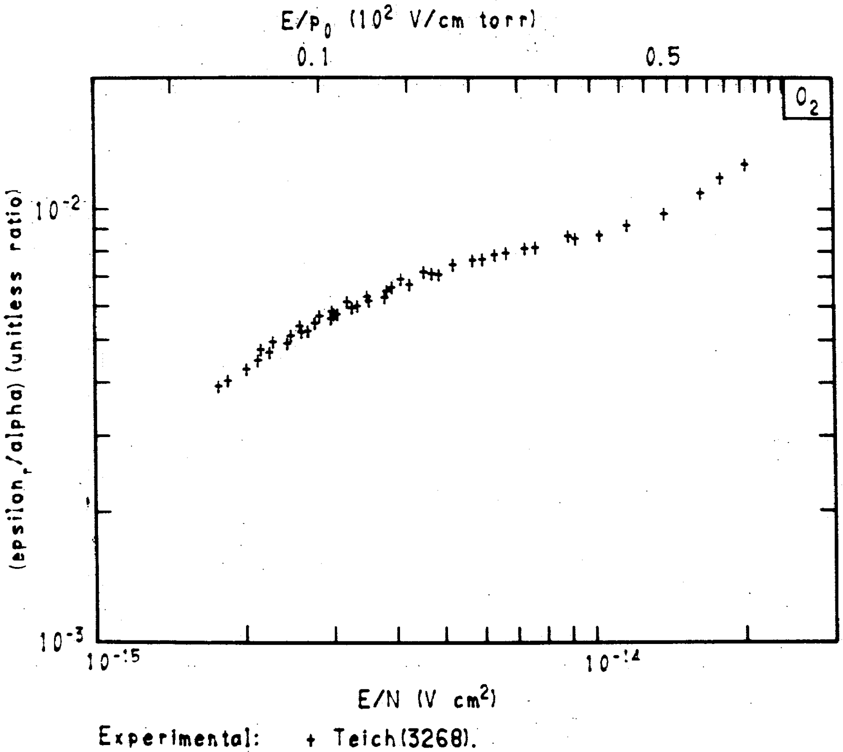


FIGURE 6.10. Experimental values of ϵ_r/α, E/N for excitation to states of oxygen leading to the emission of vacuum ultraviolet radiation.

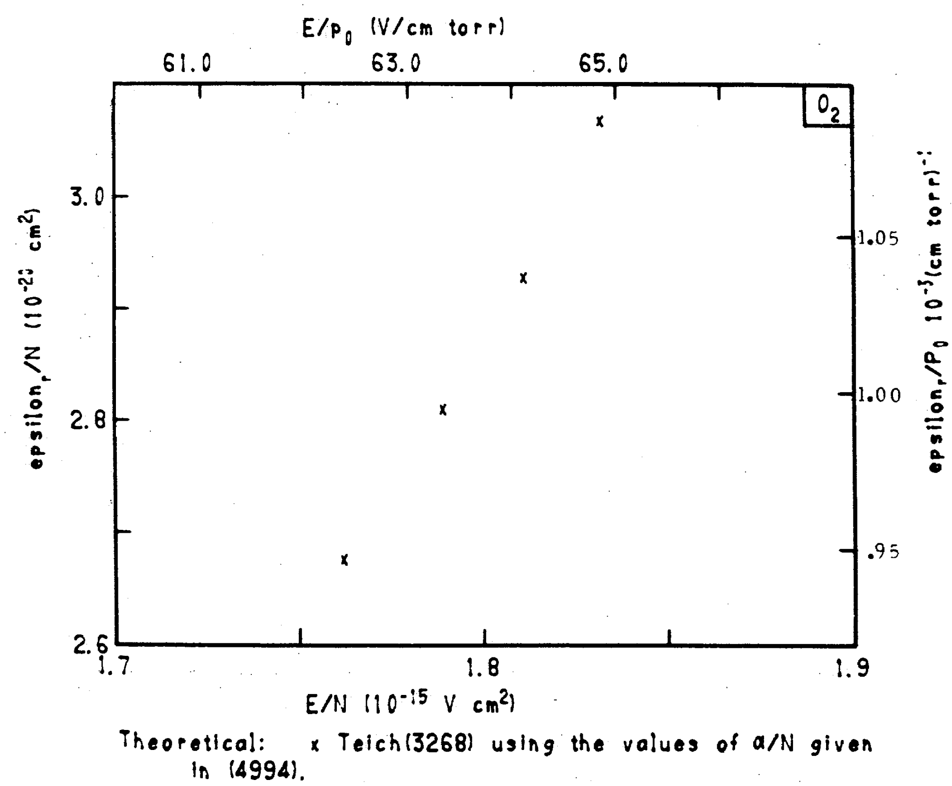


FIGURE 6.11. Values of ϵ_r/N, E/N for oxygen obtained from ϵ_r/α in [3268] and α/N in [4994].

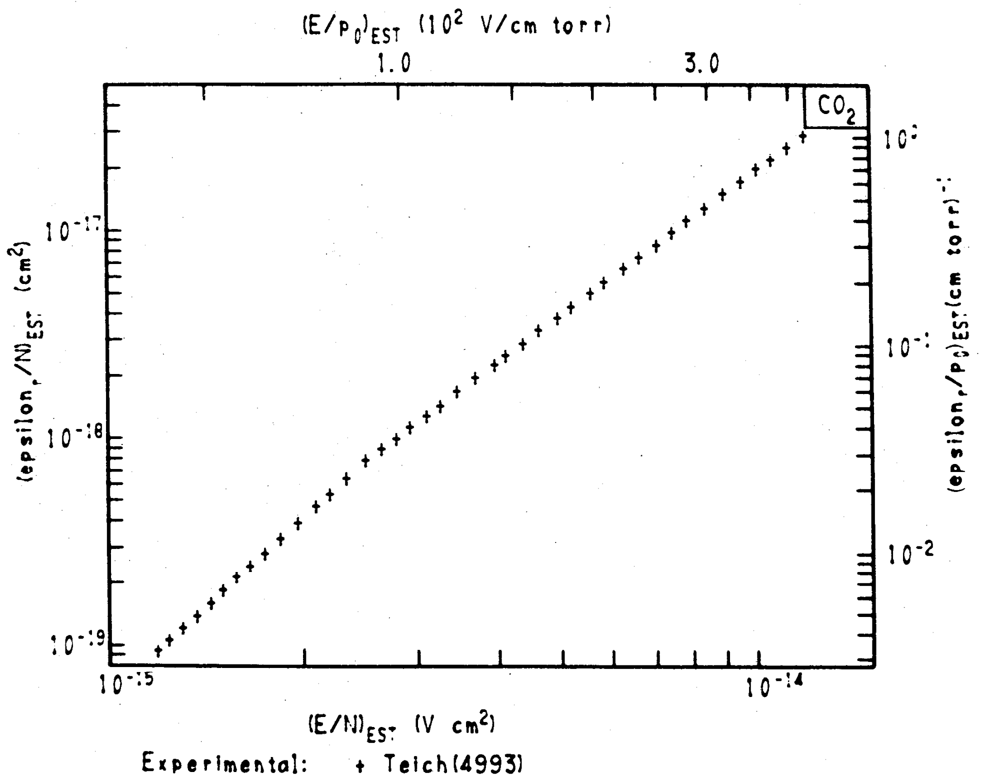


FIGURE 6.12. Experimental values of $(\epsilon_r/N)_{Est}$, $(E/N)_{Est}$ for the excitation of states of CO_2 leading to vacuum ultraviolet radiation. (A temperature of 20 °C has been assumed for converting p to N.)

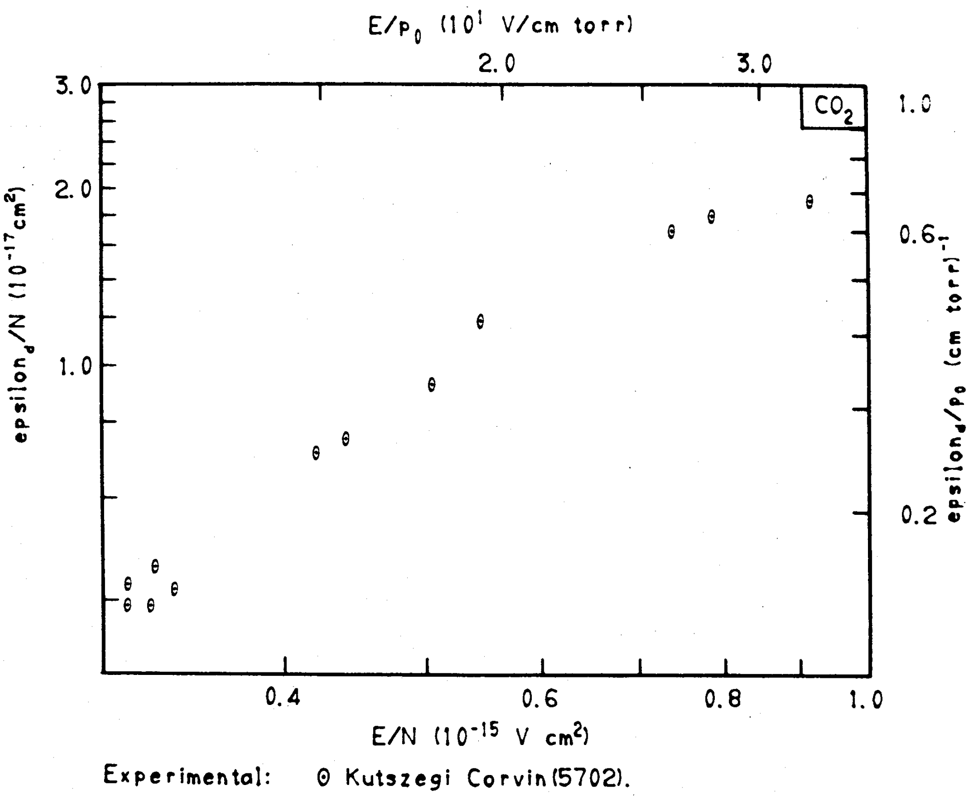


FIGURE 6.13. Experimental values of ϵ_d/N, E/N for carbon dioxide.

Table 6.1

Theoretical values of the total and partial excitation coefficients for helium*

E/N (10^{-17} Vcm^2)	ε_m/N (10^{-18} cm^2)	ε'_s/N (10^{-18} cm^2)	ε'_r/N (10^{-18} cm^2)	ε''_r/N (10^{-18} cm^2)	ε_p/N (10^{-18} cm^2)	ε_s/N (10^{-18} cm^2)	ε/N (10^{-18} cm^2)
8.8	1.54 (1)		0.067 (1)				1.61 (1)
8.96							2.67 (2)
9.1		0.236 (3)					
9.2					0.098 (3)	0.70 (3)	
9.5							1.46 (4)
9.7		0.298 (3)					
9.8	2.05 (1)		0.112 (1)				2.16 (1)
10.1					0.132 (3)	0.90 (3)	
10.4		0.38 (3)					2.62 (4)
10.7	2.60 (1)		0.218 (1)				2.82 (1)
14.23				1.92 (2)	0.86 (2)		5.8 (2)
19.7							7.9 (4)
19.8						3.7 (3)	
20.0		1.53 (3)					
20.3	6.4 (1)		1.27 (1)				7.7 (1)
20.4					0.94 (3)		
27.40				5.7 (2)	2.14 (2)		10.0 (2)
28.8							12.1 (4)
29.9						5.7 (3)	
30.3	9.2 (1)		2.37 (1)				11.6 (1)
31.5		2.27 (3)					
31.7					1.82 (3)		
39.1					2.25 (3)		
40.4							15.6 (4)
41.4		2.64 (3)					
41.6				9.4 (2)	3.4 (2)		13.0 (2)
41.7						7.1 (3)	
49.6		2.86 (3)					
50.0					2.85 (3)		
51.0						7.6 (3)	
51.2							17.7 (4)
55.9				11.6 (2)	4.5 (2)		15.2 (2)
60.1						8.0 (3)	
60.2		2.98 (3)					
60.7					3.5 (3)		
61.8							19.9 (4)
70.1				13.4 (2)	5.3 (2)		16.6 (2)
70.9							23.1 (4)
79.7							25.5 (4)
83.8				14.9 (2)	6.3 (2)		17.8 (2)
91.8							27.8 (4)
98.6				16.0 (2)	7.1 (2)		18.9 (2)
101.9							32 (4)
110						4.6 (5)	36 (5)
112.2				17.1 (2)	7.9 (2)		19.8 (2)

Table 6.1 (continued)

Theoretical values of the total and partial excitation coefficients for helium*

E/N (10^{-17} Vcm^2)	ε_m/N (10^{-18} cm^2)	ε'_s/N (10^{-18} cm^2)	ε'_r/N (10^{-18} cm^2)	ε''_r/N (10^{-18} cm^2)	ε_p/N (10^{-18} cm^2)	ε_s/N (10^{-18} cm^2)	ε/N (10^{-18} cm^2)
126.5				18.3 (2)	8.7 (2)		21.0 (2)
140.2				19.9 (2)	9.4 (2)		21.7 (2)
154.9				20.5 (2)	10.2 (2)		22.7 (2)
169.2				21.7 (2)	10.9 (2)		23.4 (2)
183.4				22.8 (2)	11.5 (2)		24.3 (2)
197.6				23.7 (2)	12.1 (2)		25.0 (2)
211.9				24.5 (2)	12.4 (2)		25.7 (2)
219						4.0 (5)	45 (5)
226.6				25.4 (2)	12.7 (2)		26.4 (2)
448						2.5 (5)	48 (5)

*ε, total excitation coefficient; ε_m, sum of excitation coefficients to the 2^3S, 2^1S and 2^3P levels; ε'_r, sum of the excitation coefficients to all states except the 2^3S, 2^1S and 2^3P levels; ε''_r, sum of excitation coefficients to all states except the 2^3S and 2^1S levels; ε_p, excitation coefficient to the 2^1P level; ε_s, excitation to the 2^3S level; ε'_s, excitation to the 2^1S level.

Theoretical:

(1) Corrigan, et al., Proc. Phys. Soc. London 72, 786 (1958).
(2) Bortnik, Sov. Phys. Tech. Phys. (Engl. trans.) 9, 1496 (1965).
(3) Phelps, Phys. Rev. 117, 619 (1959).
(4) Hughes, J. Phys. B 3, 1544 (1970).
(5) Itoh, et al., J. Phys. Soc. Japan 15, 1675 (1960).

Table 6.2

Theoretical values of the total excitation coefficient for neon

E/N (10^{-17} Vcm^2)	ε/N (10^{-17} cm^2)	E/N (10^{-17} Vcm^2)	ε/N (10^{-17} cm^2)	E/N (10^{-17} Vcm^2)	ε/N (10^{-17} cm^2)
6.59	0.39	30.3	1.45	70.2	2.87
7.63	0.44	32.5	1.57	72.5	2.96
8.80	0.49	34.5	1.62	75.1	3.0
9.85	0.55	36.3	1.71	78.4	3.1
10.89	0.61	39.3	1.81	80.7	3.2
12.07	0.66	42.3	1.92	83.0	3.2
13.50	0.74	45.4	2.08	84.7	3.3
14.81	0.80	47.2	2.14	86.7	3.4
16.12	0.86	50.3	2.21	89.3	3.5
17.82	0.96	53.1	2.34	92.1	3.6
19.39	1.03	55.7	2.41	94.6	3.7
21.10	1.08	58.3	2.48	97.5	3.7
22.67	1.16	60.7	2.55	100.1	3.8
24.37	1.26	62.5	2.63	103.5	3.9
25.94	1.31	64.9	2.71	106.9	4.0
27.91	1.37	67.3	2.79	110.5	4.0
				112.2	4.0

Theoretical:

All data taken from Hughes, J. Phys. B 3, 1544 (1970).

Table 6.3

Experimental values of the excitation coefficient for the $2^1\Pi_u$ state of hydrogen*

E/N (10^{-15}Vcm^2)	ε_r/N (10^{-17}cm^2)	E/N (10^{-15}Vcm^2)	ε_r/N (10^{-17}cm^2)	E/N (10^{-15}Vcm^2)	ε_r/N (10^{-17}cm^2)
0.460	0.069 (b)	1.142	2.06 (b)	3.47	6.1 (a)
0.532	0.181 (b)	1.220	2.39 (b)	4.14	6.5 (c)
0.608	0.34 (b)	1.293	2.63 (b)	4.84	6.7 (c)
0.666	0.66 (a)	1.356	2.92 (a)	5.33	6.4 (c)
0.686	0.53 (b)	1.369	2.90 (b)	5.94	5.9 (c)
0.766	0.71 (b)	2.062	4.2 (a)	6.05	{5.7 (c) {6.1 (c)
0.837	0.95 (b)	2.430	4.6 (c)	6.76	5.8 (c)
0.915	1.23 (b)	2.995	5.6 (c)	7.31	5.3 (c)
0.987	1.44 (b)	3.02	5.2 (c)	7.61	5.3 (c)
1.064	1.75 (b)	3.13	5.5 (c)	7.67	5.0 (c)

*a temperature of 20 C has been assumed for the results given in (a) and in (c).

Experimental:
(a) Corrigan, et al., Proc. Roy. Soc. London Ser. A 245, 335 (1958).
(b) Legler, Z. Physik 173, 169 (1963).
(c) Nygaard, J. Appl. Phys. 36, 743 (1965).

Table 6.4

Experimental values of the excitation coefficient leading to dissociation (dissociation coefficient) for hydrogen (a temperature of 20 C was assumed)

E/N (10^{-15}Vcm^2)	ε_d/N (10^{-17}cm^2)	E/N (10^{-15}Vcm^2)	ε_d/N (10^{-17}cm^2)	E/N (10^{-15}Vcm^2)	ε_d/N (10^{-17}cm^2)
0.576	1.76 (b)	0.803	4.8 (b)	1.351	9.2 (a)
0.561	2.76 (b)	1.076	5.6 (b)	1.626	9.1 (a)
0.606	2.91 (b)	1.182	5.3 (b)	2.03	4.7 (b)
0.712	3.94 (b)	1.271	7.3 (a)	3.17	21.0 (a)

Experimental:
(a) Corrigan, et al., Proc. Roy. Soc. London Ser. A 245, 335 (1958).
(b) Poole, Proc. Roy. Soc. London Ser. A 163, 424 (1937).

Table 6.5

Experimental values of the excitation coefficient for excitation to the $C^3\Pi_u$ state of nitrogen

E/N (10^{-17} Vcm^2)	ε_r/N (10^{-17} cm^2)	E/N (10^{-17} Vcm^2)	ε_r/N (10^{-17} cm^2)	E/N (10^{-17} Vcm^2)	ε_r/N (10^{-17} cm^2)
76.1	0.067	257.6	4.5	441	6.2
90.8	0.212	271.5	4.8	455	6.7
106.3	0.47	288.7	4.8	486	6.8
121.4	0.80	303	5.0	519	6.9
136.8	1.23	318	5.3	544	8.0
151.7	1.68	334	5.4	576	7.4
166.1	2.18	348	5.6	610	7.3
180.3	2.68	364	5.9	638	7.3
196.7	3.1	380	5.7	669	8.0
212.7	3.6	396	6.0	702	8.3
228.0	4.0	410	6.0	727	8.8
241.3	4.3	424	6.2	763	8.7
				822	8.8

Experimental:
All data taken from Legler, Z. Physik 173, 169 (1963).

Table 6.6(a)

Experimental values of the excitation coefficient for carbon dioxide for excitation to states leading to vacuum u.v. irradiation

E/N_{est} (10^{-17} Vcm^2)	ε_r/N_{est} (10^{-17} cm^2)	E/N_{est} (10^{-17} Vcm^2)	ε_r/N_{est} (10^{-17} cm^2)	E/N_{est} (10^{-17} Vcm^2)	ε_r/N_{est} (10^{-17} cm^2)
118.5	0.0092	249.2	0.079	555	0.50
123.5	0.0105	264.0	0.089	584	0.56
129.9	0.0120	277.7	0.100	625	0.66
136.6	0.0136	292.1	0.114	662	0.74
143.7	0.0158	309	0.128	702	0.85
149.8	0.0183	326	0.144	744	0.98
157.3	0.0211	345	0.169	783	1.12
165.4	0.0241	369	0.196	837	1.28
174.0	0.0279	394	0.226	895	1.50
184.3	0.033	411	0.251	950	1.71
195.7	0.039	436	0.286	1006	1.98
209.2	0.047	462	0.33	1058	2.19
219.6	0.053	494	0.38	1121	2.50
233.1	0.063	520	0.43	1190	2.85

Experimental:
All data taken from Teich, et al., 2nd Int. Conf. Gas Discharges, London, 335 (1972).

Table 6.6(b)

Experimental values of the dissociation coefficient for carbon dioxide

E/N (10^{-17} Vcm^2)	ϵ_d/N (10^{-17} cm^2)	E/N (10^{-17} Vcm^2)	ϵ_d/N (10^{-17} cm^2)	E/N (10^{-17} Vcm^2)	ϵ_d/N (10^{-17} cm^2)
31.2	{0.42 {0.39	33.6 42.1	0.42 0.71	54.5 73.8	1.19 1.70
32.3	0.39	44.1	0.75	78.5	1.80
32.6	0.45	50.5	0.93	91.5	1.92

Experimental:
All data taken from Kutszegi Corvin, et al., J. Chem. Phys. 50, 2570 (1969).

3.7. Ionization Coefficient

When an electron swarm moves in an electric field that is sufficiently strong for ionization of gas atoms by electrons to become significant, there is a progressive amplification of the electron current as it moves in the field direction.

When the only significant process of ionization occurring is that of gas atoms by electrons and when electron removal processes are negligible, a current I_0 released into a gas from the cathode of an electrode system in which a uniform field E is established gives rise, in the steady state, to a current

$$I = I_0 e^{\alpha(d-d_0)}, \tag{9}$$

at a distance d from the cathode. The inclusion of d_0 in eq (9) takes formal account of the fact that electrons emitted from the cathode attain a steady state, determined by the value of E/N in the gas, only after a number of collisions. The range over which eq (9) gives a satisfactory representation of the current has been discussed in detail by Folkard and Haydon [4907]. The value of d_0 decreases as N increases and thus at relatively low values of E/N, d_0 is often negligible with respect to d; in these circumstances the current is given to a very good approximation by

$$I = I_0 e^{\alpha d}. \tag{10}$$

Equations (9) and (10) define the coefficient α which is known as the Townsend primary ionization coefficient. Both experimentally and theoretically α/N is found to be a function of E/N so that α is constant for a given value of N and E/N. When primary ionization is the only significant process, α may clearly be determined from measurements of the steady-state ionization current as a function of d at constant E/N and N by using eq (9) or (10). This method of determining α is usually referred to as the Townsend method. The primary ionization coefficient may also be determined from measurements on the transient electron avalanche produced by a pulse of electrons released from the cathode of a uniform-field electrode system. If a number n_0 electrons is released in the pulse, the number of electrons in the gap at any time t less than the transit time of the electrons across the gap is given by

$$n = n_0 \exp(\alpha W_- t). \tag{11}$$

This equation may be used as the basis for obtaining values of αW_- by determining the electron component of the transient current in the gap from measurements either of the current in the external circuit of which the gap forms part, or of the light emission from the gap as a function of time. The total duration of the electron component of the avalanche gives the value of W_- and hence α may be obtained. If each avalanche is initiated by only one electron from the cathode, there is a measureable statistical fluctuation in the total number of electrons produced in an avalanche. Measurements of the probability $f(n)$ of such a single avalanche containing a total number n electrons may also be used to determine α, since

$$f(n) = (\bar{n})^{-1} \exp(-n/\bar{n}), \tag{12}$$

where $\bar{n} = \exp(\alpha d)$.

The interpretation of the Townsend primary ionization coefficient, defined by eq (9), in terms of ionization rate coefficients and of ionization coefficients per unit distance in the direction of the electric field depends on whether or not diffusion is significant. The effects of diffusion can often, in practice, be neglected and in this case the ionization coefficient α can be interpreted such that the number of new electrons produced on the average by n electrons in moving a distance dx in the field direction is $n\alpha dx$, i.e. α is a coefficient per unit drift distance as discussed in section 2. It should be remembered, however, that if diffusion is taken into account the number of new electrons produced on average by n electrons moving a distance dx in the field direction becomes (Crompton, J. Appl. Phys. **38**, 4093, 1967)

$$n\alpha[1 - \alpha(D/W)]dx = n\alpha_i dx, \tag{13}$$

say. Thus, strictly, the ionization frequency $\nu_i = \alpha_i W$, and only when diffusion can be neglected can the approximation $\nu_i = \alpha W$ be used.

This can be important when relating data on ionization coefficients to the ionization cross section $Q_i(\epsilon)$ through the relationship

$$\nu_i = \int_{\epsilon_i}^{\infty} (e/150m)^{1/2} N Q_i(\epsilon) \epsilon^{1/2} F(\epsilon) d\epsilon, \qquad (14)$$

where ν_i is the ionization frequency, ϵ_i the ionization energy, ϵ the electron energy and $F(\epsilon)$ the normalized electron energy distribution. It should also be borne in mind when comparing the results of measurements of steady-state growth of prebreakdown ionization currents (Townsend method) with those of pulse analysis and of high frequency breakdown measurements.

Where available, values of the Townsend primary ionization coefficient obtained by both steady state and pulse methods are given in the following subsections. Somewhat different problems are encountered in obtaining values of the coefficients for monatomic gases, for molecular gases which are not electronegative, and for electronegative gases. The data are thus grouped under these headings.

3.7.a. Ionization Coefficient—Monatomic Gases

In monatomic gases, eq (9) is not a good approximation to the prebreakdown ionization current, because secondary ionization, which results from a number of possible secondary ionization processes, is always significant compared with primary ionization. In these circumstances, the steady-state ionization may be expressed as

$$I = I_0 e^{\alpha d} / [1 - (\omega/\alpha)(e^{\alpha d} - 1)], \qquad (15)$$

where ω/α is a coefficient representing the action of secondary ionization processes. Hence, by suitable analysis, values of α can be obtained from measurements of steady-state ionization currents as a function of d at a constant value of E/N. Care is needed in the use of eq (15), however. For a number of secondary ionization processes (such as the emission of electrons at the cathode by positive ions, for example) ω/α is, or can effectively be treated as, a constant at a given value of E/N but for others (such as emission of electrons from the cathode by metastable atoms) the dependence of ω/α on d has to be considered.

Moreover, monatomic gases have large excitation and ionization potentials relative to other gases, so that experimentally, it is necessary to use gas samples of the highest possible purity if significant data relating to the gas being investigated are to be obtained.

3.7.a(i). Ionization Coefficient—Helium

The problem of gas purity is acute in the case of helium which has an ionization potential (24.58 V) higher than that of any other gas, and metastable levels with energies above 19.8 eV. As a result, any impurities present are not only preferentially ionized by direct ionization but are also ionized by Penning ionization which occurs in collisions between helium metastables and impurity atoms. The high cross section for Penning ionization means that very small concentrations of impurity (~p.p.m.) can significantly affect the spatial growth of ionization. For this reason the values obtained for α in helium have decreased as vacuum techniques have improved.

The recent experimental results [646, 1173] given in figure 7.1(a) and table 7.1 were obtained using modern ultrahigh vacuum techniques and it is significant that there is good agreement between the two sets of data. There is, moreover, good agreement for $E/N > 17 \times 10^{-17}$ V cm^2 between these experimental data and the theoretically computed values, some of which are also shown in figure 7.1(a). An intercomparison of the available theoretical data obtained using both analytical methods [771, 1440, 2143, 5701, 4909] and Monte Carlo techniques [3897] is shown in figure 7.1(b).

It should be noted that recent experiments using He and Ne–He mixtures [3751] indicate that the generally accepted experimental values for helium may still be too large, not because of impurities but because of the operation of processes which do not conform to eq (13) where a constant value of ω/α is used to analyze the data.

Values of E/N below about 17×10^{-17} V cm^2 correspond to relatively large electrode separations and to high gas pressures so that experimental problems, especially those associated with the production of some litres of very high purity gas, become severe. Recent work [4910, 5077, 4049] in this range has shown that even for impurity contents as low as about 1 p.p.m., the values of α/N obtained are considerably higher than those expected for pure helium, because of the influence of Penning ionization. Earlier values are even higher [2406] probably because of relatively high levels of neon impurities or unreliable [646] because of the restricted range of parameters used. In these circumstances, the most reliable data available for α/N for $E/N < 1.7 \times 10^{-16}$ V cm^2 are probably those obtained by theoretical computations and shown in figure 7.1(b), although even these are subject to uncertainties due to the approximations adopted and uncertainties in the cross sections used [*see* 3753]. Table 7.1 gives a composite set of values of α/N in helium over the full range investigated.

At values of $E/N > 2.84 \times 10^{-15}$ V cm^2 which correspond to very low values of pressure and electrode separation, experiment [646] indicates that electrons do not experience sufficient collisions in moving from cathode to anode for steady-state conditions to be established and in these circumstances values of α have little significance.

3.7.a(ii). Ionization Coefficient—Neon

The experimental results of Kruithof and Penning [2355], which were themselves in fair agreement with the earlier results of Townsend and MacCallum [730] at an unspecified temperature, have been confirmed by three recent sets of measurements [751, 3751, 3612] in which ultrahigh vacuum techniques were used. The data of Kruithof and Penning together with the three recent sets of data are given in figure 7.2 and in table 7.2. (To avoid confusion two graphs—figs. 7.2(a) and (b)—are shown with one set of values [2355] common to both.) Measurements of the luminous flux from self-sustaining discharges in neon as a function of distance from the cathode gave values of α/N lower than those obtained by the Townsend method both for pure [2535, 5049] and impure [5771] neon. The reasons for this difference are not at present clear and the results for pure neon using this method seem to depend on the conditions since one set of data [2535] gave results of 20 to 30 percent below those given in figure 7.1, while another [5049] gave results about 16 percent below those in figure 7.1.

In attempting to obtain theoretically computed values of α/N in neon, one of the main difficulties is in the uncertainty associated with values of the excitation cross section as a function of energy. It has been shown in a number of investigations [2048, 5110, 4909] that the experimental values of this cross section obtained by Maier-Leibnitz (Z. Physik **95**, 499, 1935), gave calculated values of α/N in fair agreement with experiment. In recent more rigorous calculations, values of α/N were obtained using Monte Carlo calculations [3752] and using the energy distribution obtained from the solution of the Boltzmann equation [3753]. In this work it was found necessary to use excitation cross sections about 20 percent less than the Maier-Leibnitz experimental values in order to obtain the agreement between the theoretical and experimental values of α/N shown in figure 7.2.

The largest experimental uncertainty lies in the region of E/N below about 1.5×10^{-16} V cm^2 which is also the region in which there is discrepancy between theory and experiment as shown in figure 7.2(b).

Both theory [3752] and experiment [751] agree in indicating that above a value of E/N of about 2.82×10^{-15} V cm^2, steady-state conditions are not established so that the concept of a swarm coefficient α is not relevant.

3.7.a(iii). Ionization Coefficient—Argon

The most extensive investigations of argon to date are those of Kruithof and Penning [2139] and Kruithof [2237] with which the more recent data obtained over restricted ranges by Davies and Milne [2138] and by Willis [5241] are in good agreement as can be seen from figure 7.3. Kruithof's data are given numerically in table 7.3.

There has been no estimate of the upper limit of E/N for which equilibrium swarm conditions are likely to occur, but Kruithof [2237] remarked that although the region of the I, d curve satisfying eq (10) became shorter and shorter as E/N increased, it was possible to determine α/N at values of E/N up to 4.7×10^{-14} V cm^2.

At low values of E/N, the experimental error in the values of α/N obtained by Kruithof and Penning increases considerably because of the relatively low pressures ($160>p_0>1$ Torr) and small electrode separations ($d<1.6$ cm) used. The uncertainty in the region of $E/N<34\times10^{-17}$ V cm^2 is further increased by the recent work of Golden and Fisher [2333] at higher pressures (up to 700 Torr) and large electrode separations (up to 5 cm). They found that the I, d curves could not be represented by eq (15) but that values of α/N could be obtained, from measurements of I as a function of p_0 at a constant value of d; the values of α/N obtained, however, depended on the distance used. The values of α/N at all values of d (0.6 to 1.2 cm) used for $34\times10^{-17}>E/N>25\times10^{-17}$ V cm^2 were within 20 percent of the values of Kruithof and Penning. For $E/N<25\times10^{-17}$ V cm^2, on the other hand, the values which were obtained for $d=4$ and 5 cm were lower than those of Kruithof and Penning by as much as a factor of 15 at $E/N=14.1\times10^{-17}$ V cm^2.

Although the results of theoretical computations, which are also shown in figure 7.3, are close to the experimental values they were obtained by methods open to the general criticism of Thomas [3753] concerning similar computations for neon.

3.7.a(iv). Ionization Coefficient—Krypton and Xenon

The two available sets of data [2237, 5293] for krypton are shown in figure 7.4. There is good agreement for $E/N>100\times10^{-17}$ V cm^2 but the recent results of Heylen [5293] fall increasingly below those obtained by Kruithof [2237] as E/N decreases, being about a factor of two lower at $E/N\sim30\times10^{-17}$ V cm^2. Numerical values from both sets of data are given in table 7.4(a).

The only data available for xenon are the experimental values obtained by Kruithof [2237] shown in figure 7.4 and given in table 7.4(b).

3.7.b. Molecular Gases Which Are Not Electronegative

In molecular gases the secondary ionization coefficient ω/α is considerably smaller in relation to the primary ionization coefficient than is the case in monatomic gases. Thus, in some circumstances, eq (9) can be used to determine α by the Townsend method but in other cases it has been shown [2150] that significant errors can be introduced if the full eq (15) is not used to analyze the data.

The relatively low value of ω/α also means that relatively large electron avalanches can develop in molecular gases at distances less than the distance d_s at which breakdown occurs, d_s being given by the value of d at which the denominator of eq (15) becomes zero. This simplifies the experimental problems associated with the measurement of the electron component of transient electron avalanches, so that for molecular gases values of α have often been obtained both by the Townsend method and the methods based on measurements on transient avalanches (see sec. 3.7). The values for H_2 and N_2 using both methods are given and compared in the next two sections.

3.7.b(i). Ionization Coefficient—Hydrogen

The question of purity is not nearly as critical in hydrogen as in the inert gases [790]. As a result, there is good agreement between the values obtained in a large number of experimental determinations based on the measurement of steady-state currents [751, 782, 790, 1145, 1160, 1174, 1356, 1640, 2148, 2150], of pulsed avalanches [2154] and of radiation from self-sustaining discharges [5105] for values of $E/N \lesssim 3.4\times10^{-15}$ V cm^2. The data obtained in this range are so numerous that for clarity they are shown in two figures, 7.5(a) and 7.5(b), with one set of points [1356] common to both to aid the comparison. These data are also given in table 7.5.

By numerical solution of the Boltzmann equation, Engelhardt and Phelps obtained values for the appropriate collision cross sections which, as shown in figure 7.5, gave computed values of α/N in good agreement with the experimental data, although some of the cross sections used need modifying to take account of subsequent experimental data (Phelps, Rev. Mod. Phys. **40**, 399, 1968).

Until recently the situation for values of $E/N \sim 3.4\times10^{-15}$ V cm^2 was confused, there being a large number of observations, extending in some cases up to values of $E/N > 3\times10^{-14}$ V cm^2, with discrepancies between results of different investigations which increased as E/N increased. The situation has, however, been considerably clarified by the recent investigation of Folkard and Haydon [4907] in which special attention was paid to the effect of instrumental errors on the accurate determination of the ionization currents and to considerations of the range of experimental parameters over which a steady state is established. This work showed that significant values for α/N can be obtained only up to values of E/N about 7×10^{-15} V cm^2. At higher values of E/N in the range $8\times10^{-15} \leq E/N \leq 14\times10^{-15}$ V cm^2, a quasi-steady state exists as shown by Monte Carlo calculations [5292]. When a steady-state analysis is used to analyze results obtained in this region the values of α/N obtained vary greatly, depending on the precision with which the ionization currents are measured. The region of $E/N \gtrsim 14\times10^{-15}$ V cm^2 is a completely non-steady-state region to which the concept of swarm coefficient α is not relevant.

Accordingly, the values obtained in various investigations up to $E/N = 7\times10^{-15}$ V cm^2 are shown in figure 7.6. In this region Jones and Llewellyn-Jones [2150] and Haydon and Stock [2148] have shown, respectively, that ignoring secondary ionization in the analysis of experimental data and including measurements at small distance when field distortion occurs, both give rise to high values of α/N. Other results [1160] show that the purity of the gas sample plays a significant role in this region. These factors probably contribute to the remaining discrepancies. The numerical values given in table 7.5 for $E/N > 3.4\times10^{-15}$ V cm^2 are those of Folkard and Haydon [4907] since they are likely to be the most accurate obtained to date.

3.7.b(ii). Ionization Coefficient—Nitrogen

The results of recent investigations of steady-state ionization currents [1145, 1741, 1836, 1948, 2144, 2275, 5187] and pulsed avalanches [1836, 2154, 5228], at values of E/N below about 2.82×10^{-15} V cm^2, using samples of nitrogen from cylinders (usually with impurity contents of about 0.1 percent) in conventional vacuum systems using backing and diffusion pumps, from which mercury was excluded, are in fairly good agreement with each other. In view of the large number of results available they are plotted for clarity on two figures—7.7(a) and 7.7(b)—with a set of data obtained from measurements of steady-state ionization for samples of higher purity [710] included in both figures to facilitate comparison. These values are also in fair agreement with the earlier data of Masch [2277, 2556] (if it is assumed that the temperature of Masch's measurements was 20 °C) even though it is likely that Masch's results were for mercury-contaminated gas.

Englehardt, Phelps, and Risk [218] were able to find a self-consistent set of collision cross sections which, as shown in figure 7.7(a), give computed values for the ionization coefficient in agreement with the experimental values shown.

It has been clear for some time that small amounts of impurities (<0.1 percent) significantly affected the results obtained in the range of E/N below 2.82×10^{-15} V cm^2 in nitrogen. For example, Harrison [2102] using a degassed conventional vacuum system, obtained large (3 to 30 percent) differences in results for gas samples produced in different ways, the values in all cases being considerably greater (by two to six times) than those shown in figure 7.7. On the other hand, Heylen [710], using an ultrahigh vacuum system found that, although his values for α/N were higher than the others shown in figures 7.7(a) and (b) for values of $E/N < 1.3\times10^{-15}$ V cm^2, they lay much closer to them; for example, at $E/N \simeq 1\times10^{-15}$ V cm^2, Heylen's value is about 40 percent higher, whereas Harrison's data lie between a factor of three and four higher. Recent investigations [5334, 5703] have shown that these differences result from the fact that in nitrogen the emission of electrons from the cathode by metastable nitrogen molecules (Haydon, J. Phys. B **6**, 227, 1973) can make an important contribution to the secondary ionization. This process gives rise to a secondary ionization ω/α which is dependent on electrode separation. Thus, primary and secondary ionization acting together can, in some circumstances, give an exponential spatial growth of current which if analyzed by means of eq (9), which assumes that primary ionization alone is operative, gives erroneously high values of α/N. Thus the values of α/N shown in figure 7.7 which are obtained for slightly impure samples are more likely to be characteristic of nitrogen, because the impurities quench the metastables, thus markedly changing the secondary ionization, but having little effect on the primary ionization. This supposition is confirmed by the agreement of the values obtained from steady-state measurements on such samples with those obtained from pulse measurements [2154, 5228] which are not affected by secondary ionization.

A composite set of experimental results excluding the data of [2275] at the upper end and of [710] at the lower end of the ranges are given in table 7.6.

There are three recently published sets of data [3297, 2448, 5334] in mercury-free nitrogen for $E/N > 2.82 \times 10^{-15}$ V cm^2. These are compared with Bowls' [2275] earlier values in figure 7.8. The values are not very different from those obtained for mercury-contaminated nitrogen [789, 2277 and 2556]. The most recent investigation [5334] shows that all these data correspond to the steady-state region which was shown to extend to $E/N \simeq 3.4 \times 10^{-14}$ V cm^2 in nitrogen.

3.7.c. Electronegative Gases

In electronegative gases, processes of electron attachment to and detachment from gas molecules have to be taken into account, and ion conversion reactions which convert negative ions of species A^-, with a low cross section for collisional detachment, to species B^- with high cross section or vice versa can also be important. The equation for the spatial growth of prebreakdown ionization taking into account these processes in addition to primary and secondary ionization processes, may be written as

$$I = I_0 \frac{\alpha\left(\frac{\lambda+\delta+\kappa}{\lambda_1(\lambda_1-\lambda_2)}\right)e^{\lambda_1 d} - \frac{\alpha(\lambda_2+\delta+\kappa)}{\lambda_2(\lambda_1-\lambda_2)}e^{\lambda_2 d} + \frac{[(\eta+\eta^1)\kappa+\eta\delta]}{\lambda_1\lambda_2}}{1-\left(\frac{\omega}{\lambda_1-\lambda_2}\right)\left[\left(\frac{\lambda_1+\delta+\kappa}{\lambda_1}\right)\left(e^{\lambda_1 d}-1\right)-\left(\frac{\lambda_2+\delta+\kappa}{\lambda_2}\right)\left(e^{\lambda_2 d}-1\right)\right]} \qquad (16)$$

where η, η^1 are electron attachment coefficients to form A^- and B^- ions respectively, δ the electron detachment coefficient from ion species B^- (that from A^- being taken as negligibly small) and κ the ion conversion coefficient from A^- to B^- ions (all coefficients being per unit drift distance). The coefficients λ_1 and λ_2 are the roots of the equation

$$\lambda^2 - (\alpha - \eta - \eta^1 - \delta - \kappa)\,\lambda - [(\alpha - \eta - \eta^1) \times (\kappa + \delta) + \eta^1\delta] = 0. \qquad (17)$$

Analysis of experimental data in terms of eq (16) which contains seven unknown coefficients is difficult and this equation has not so far been used for the analysis of data in any published work. Analysis using the simplified equation obtained by assuming the formation of only one ion species and neglecting secondary ionization has been carried out, but even in this case the combinations of values of the coefficients (α, η, δ) which will give agreement with the experimental data are in general subject to inherently large spreads (typically ~ 100 percent) even when the measurements of the ionization currents are accurate to within a few percent.

In practice, there is often a range of distance for which all but the first terms in the numerator and denominator of eq (16) are negligible. Over this range a graph of log I, d is linear with a slope λ_1. Under similar conditions, avalanches grow temporally with a time constant $\lambda_1 W_-$ so that λ_1 can be obtained both from steady state and pulse measurements.

The coefficient λ_1, which can be thought of as an apparent or effective ionization coefficient, is a useful measure of the electrical properties of an electronegative gas and, unlike the true ionization coefficient α, can always be determined to within a few percent provided the ionization currents are measured accurately (to within a few percent) over a sufficiently wide range. Consequently, for the electronegative gases values of λ_1/N are given rather than values of α/N even though λ_1/N is often a function of N as well as of E/N. (In some cases the values presented have had to be recovered from the data given in the published papers by combining graphs and taking into account the analysis used.)

3.7.c(i). Apparent Ionization Coefficient—Oxygen

Recent investigations in oxygen have been confined to $E/N < 200 \times 10^{-17}$ V cm^2. The values of λ_1 obtained are shown in figure 7.9. For clarity two graphs, figures 7.9(a) and 7.9(b), have been drawn with the theoretical values given on each to aid comparison. It can be seen that the values obtained using the Townsend method [573, 791, 861, 961, 2555, 2908] and those obtained using pulse [2154, 2387] methods show general agreement within rather a large scatter which is greatest at the lowest values of E/N. Some of this scatter may be accounted for by the fact that in a recent investigation [2908] in this region λ_1/N was shown to be dependent on N as well as E/N, a fact attributed to the occurrence of three-body processes which influence λ_1.

Hake and Phelps [2553] were able to obtain a set of self-consistent cross sections which give theoretically computed values of λ_1/N which, as shown in figure 7.9, lie within the spread of the experimental data.

Use has recently been made [4994] of the fact that the addition of small percentages of hydrogen to oxygen gives a gas mixture which, because of the fast associative detachment reaction

$$O^- + H_2 \rightarrow H_2O + e,$$

behaves as nonattaching gas, in which the true ionization coefficient can be accurately determined. Theoretical calculations showed that the energy distribution of the electrons remained unchanged in the mixture so that the values of α/N obtained for the mixture should thus correspond to the true ionization coefficient for O_2. These values which lie within the large spread of values determined from the analysis of measurements in oxygen alone are shown in figure 7.9(c).

There is only one extensive published set of data [2556] extending beyond $E/N = 200 \times 10^{-17}$ V cm². These results, which were obtained for oxygen contaminated with mercury vapor from the manometer used, are shown in figure 7.10. The temperature corresponding to the values of E/p and λ_1/p given in the original paper is not clear and a value of 20 °C has been assumed to obtain the data in figure 7.10. Frommhold [2154] gives two values for oxygen uncontaminated with mercury vapor at $E/N = 239 \times 10^{-17}$ and 326×10^{-17} V cm², and these are also shown in figure 7.10.

No estimates have been made of the value of E/N above which steady-state swarm conditions cease to exist.

3.7.c(ii). Ionization Coefficient—Carbon Monoxide

The results of electron beam experiments have shown that negative ions are formed by electron collisions with gas atoms in carbon monoxide by processes such as

$$CO + e \rightarrow C + O^-.$$

The processes are relatively high energy processes (thresholds ~ 10 eV), however, and do not give rise to significant attachment in electron swarms for the range of values of E/N up to about 300×10^{-17} V cm² for which determinations have been made. (See sec. 3.4.c.) Thus the coefficient determined from the linear section of the log I, d graphs in carbon monoxide represents a true ionization coefficient. The values obtained in the three published investigations [1254, 4016, 5243] are shown in figure 7.11 and tabulated in table 7.7.

There are no published values of α/N in carbon monoxide for values of $E/N > 275 \times 10^{-17}$ V cm².

3.7.c(iii). Apparent Ionization Coefficient—Nitric Oxide

There is no published information available on the ionization coefficient for nitric oxide.

3.7.c(iv). Apparent Ionization Coefficient—Carbon Dioxide

In contrast to the situation in carbon monoxide, there is no doubt that electron attachment occurs in low energy swarm conditions in CO_2 and there have been four recent determinations of apparent ionization coefficients in this gas, two [948, 3435] using the Townsend method and two [1625, 1724] using pulse methods. The apparent ionization coefficient has been shown [3435] to be independent of gas number density for $35 \times 10^{16} < N < 1062 \times 16^{16}$ cm^{-3}, and the result of the four investigations are in good agreement as is shown in figure 7.12.

Hake and Phelps [2553] obtained a set of cross sections that gives theoretically computed values of λ_1/N which, as shown in figure 7.12, agrees with the experimental data.

There is one set [948] of recent data for λ_1/N in CO_2 for $E/N > 282 \times 10^{-17}$ V cm² and this is compared with the early values of the Townsend group [2271, 2593, 2815] and of Bishop [3490] in figure 7.13. The theoretical data of Hake and Phelps [2553] are included in this figure also to aid comparison. It can be seen that in the region where the results overlap, the data of the Townsend group lie considerably closer to the more recent results both of figure 7.12 and of [948] than those of Bishop. Table 7.8, which gives the numerical data, includes all the results shown in figure 7.12, together with the data of Townsend [2271] and of Bhalla and Craggs [948] for $E/N > 152 \times 10^{-17}$ V cm² and of Hurst [2815] for $E/N > 4000 \times 10^{-17}$ V cm².

No estimate has been made of the upper limit to the value of E/N at which steady-state conditions exist in CO_2.

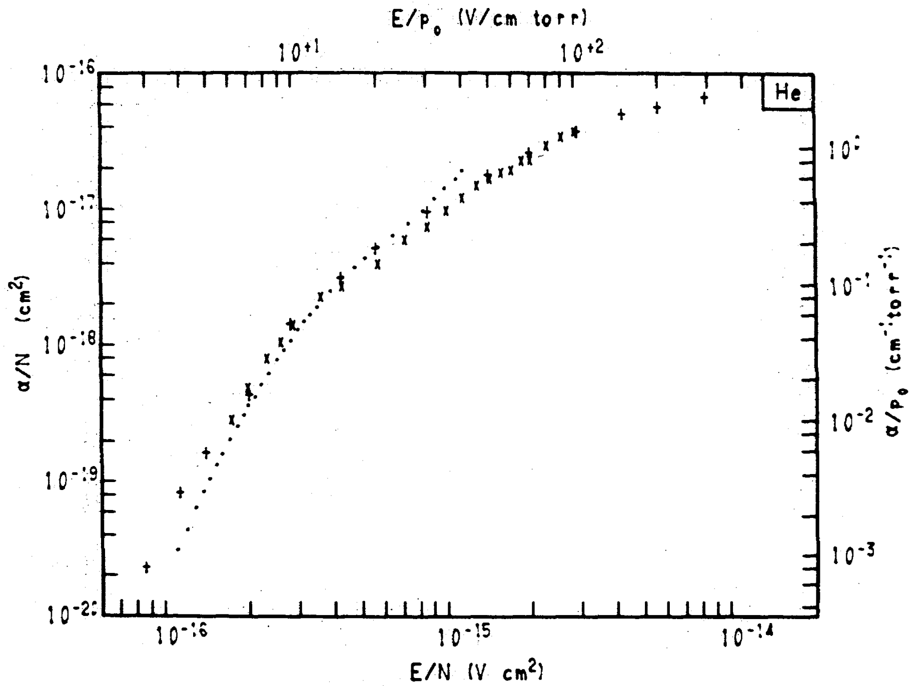
3.7.c(v). Apparent Ionization Coefficient—Air

For values of $E/N < 1.7 \times 10^{-15}$ V cm², a number of sets of experimental data for λ_1/N in dry air uncontaminated with mercury vapor have been obtained. The values obtained using the Townsend method are given in figure 7.14.

It can be seen that although the general trend of the various sets of results is the same, there is considerable scatter in the data. Some of this scatter, particularly at the lower values of E/N, is due to the variation of λ_1/N with N at a given value of E/N which has recently been shown [4015] to occur, and which is illustrated in figure 7.15.

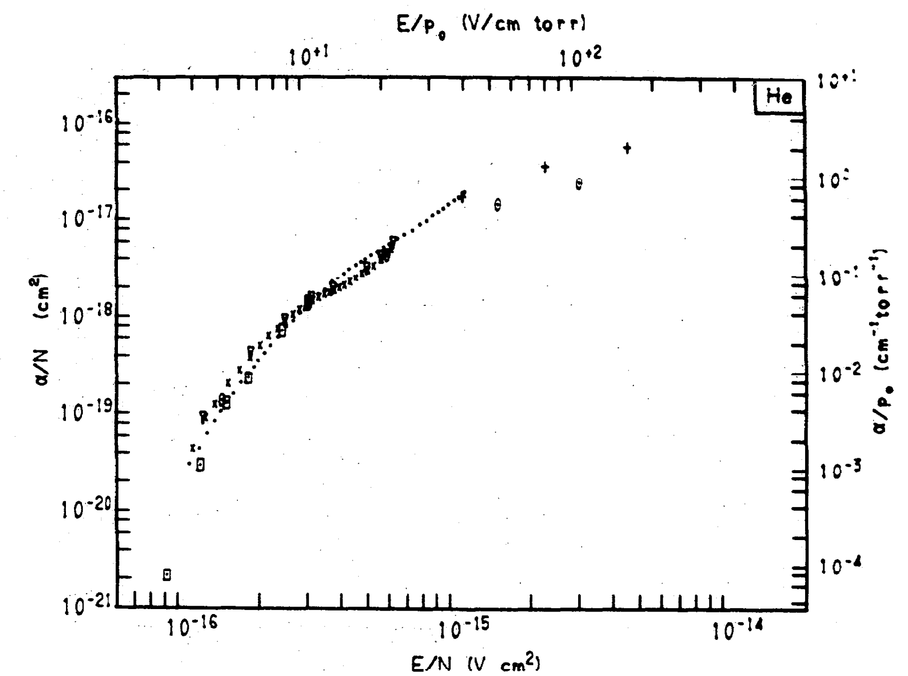
The only results obtained using a pulsed avalanche method [1911] are between about a factor of two and ten lower than the results shown in figure 7.14. There are no published theoretical values of λ_1/N for air.

The two investigations [2274, 2556] of air which cover the widest range of E/N and which extend well beyond the value of $E/N = 1.7 \times 10^{-15}$ V cm² were both carried out using mercury-contaminated air, but give results, as can be seen from figure 7.16, lying close to those obtained in a recent investigation [5246] of mercury-free, dry air. Consequently the three sets of results are given in table 7.9. No estimate appears to have been made of the value of E/N above which steady-state swarm conditions cease to exist.



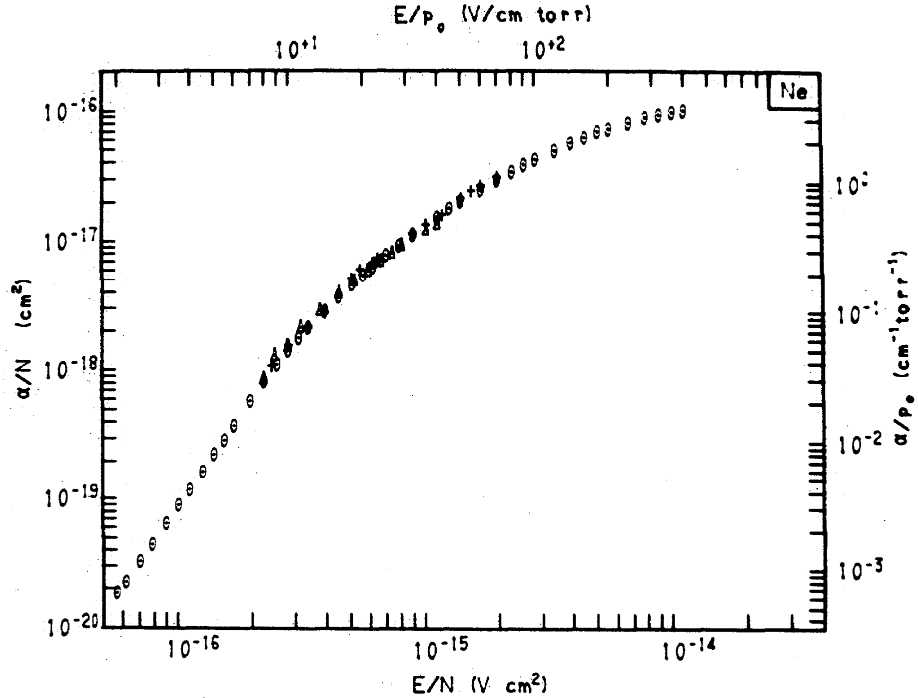
Experimental: + Chanin(646); x Davies(1173).
Theoretical: • Hughes(4909).

FIGURE 7.1.(a) α/N, E/N for helium.



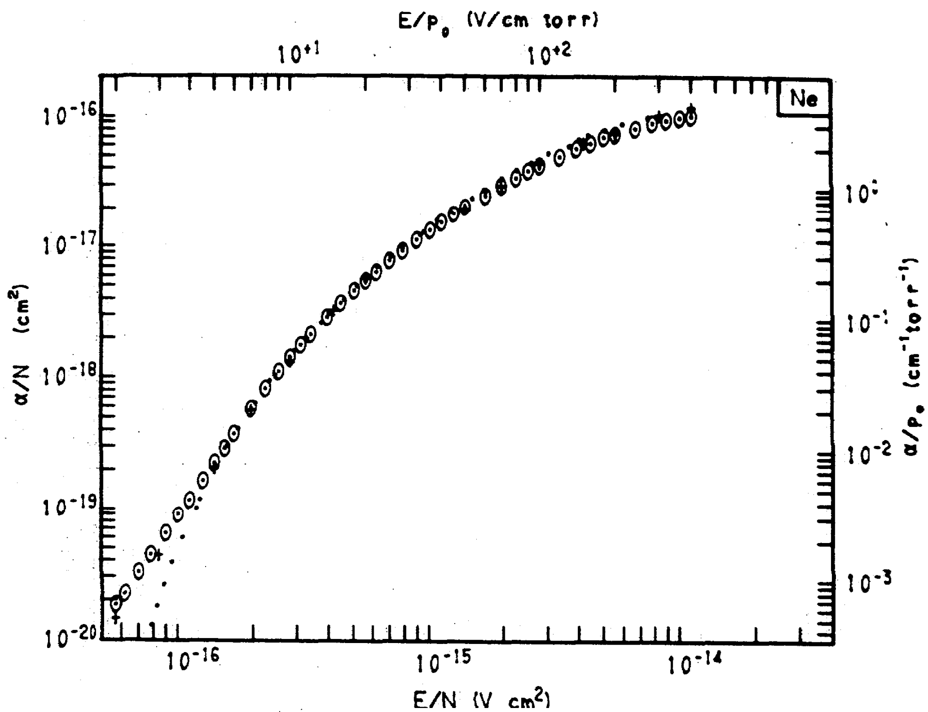
Theoretical: ∇ Phelps as given in Chanin(626); ⊡ Dunlop(771);
⊙ Heylen(1440); Δ Abdelnabi(2143); • Hughes(4909);
+ Itoh(3897); x Phelps(5701).

FIGURE 7.1(b). Theoretical α/N, E/N for helium.



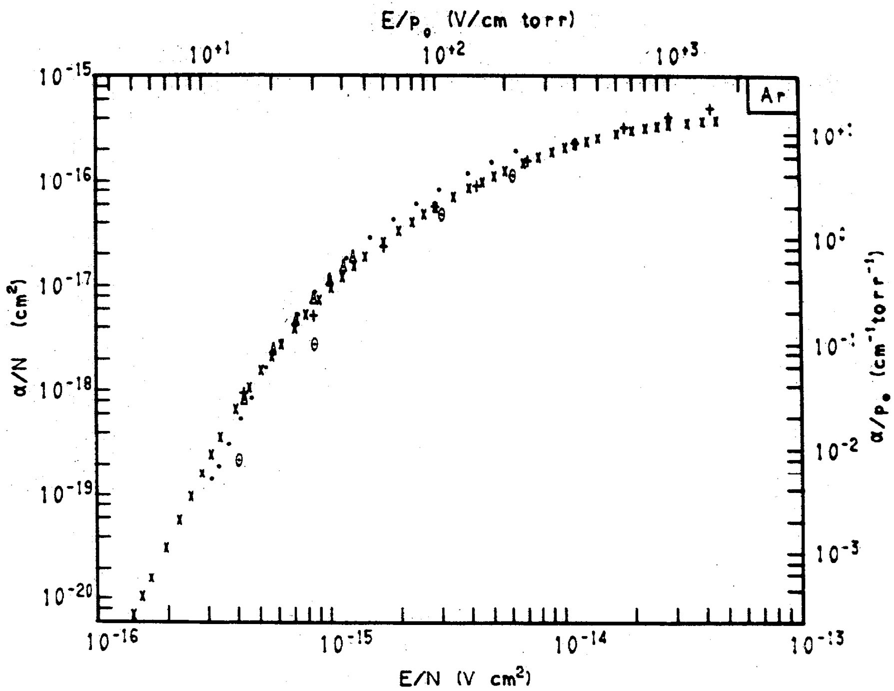
Experimental: ⊙ Kruithof(2355); + Willis(3612); △ Dutton(3751).

FIGURE 7.2(a). α/N, E/N for neon.



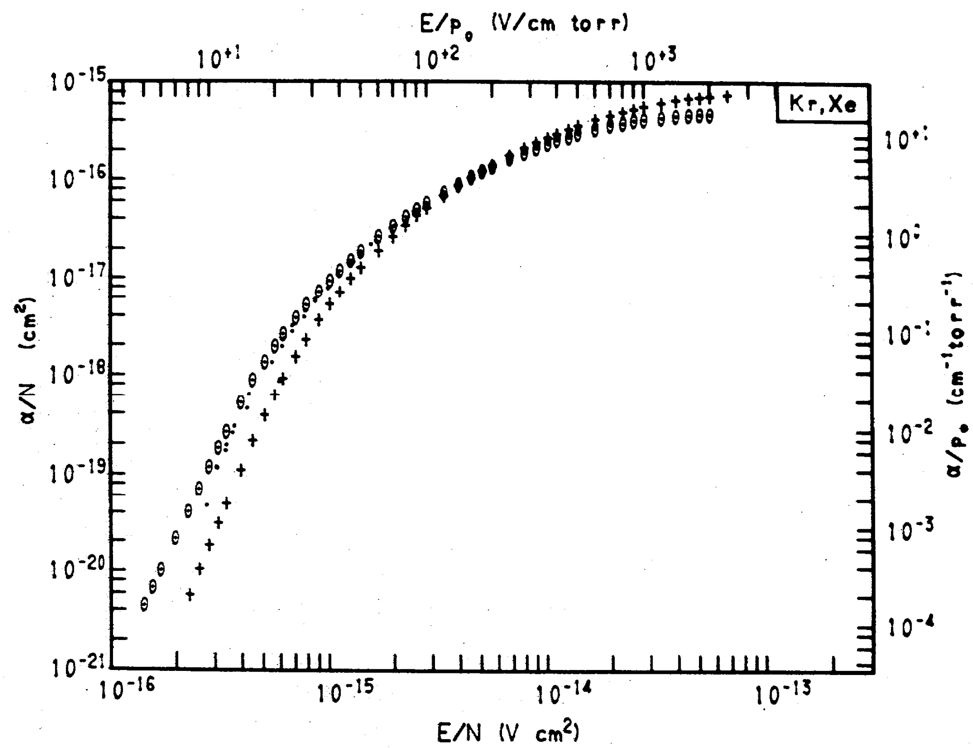
Experimental: + Chanin(751); ⊙ Kruithof(2355).
Theoretical: • Thomas(3753).

FIGURE 7.2(b). α/N, E/N for neon.



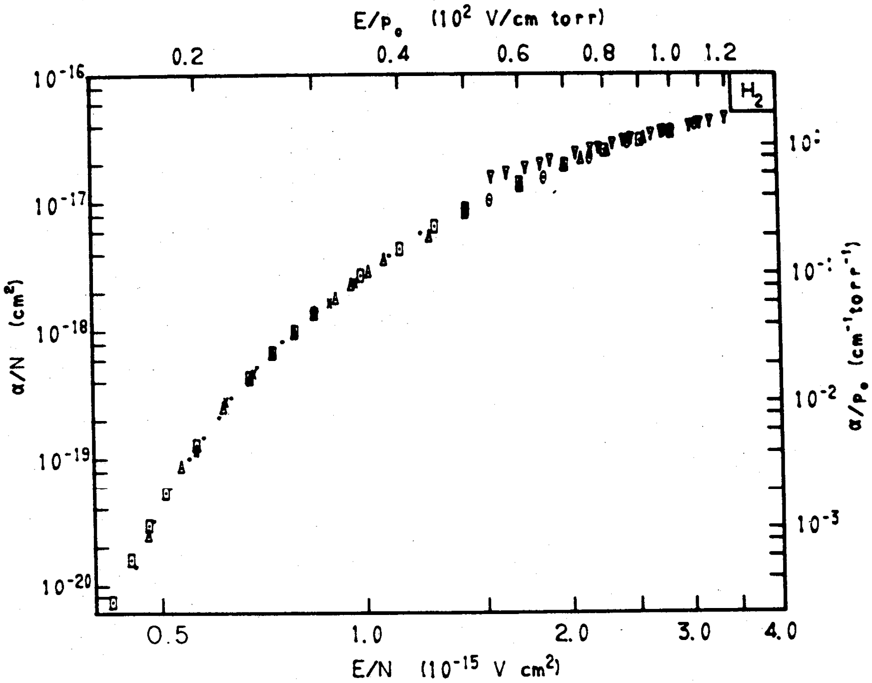
Experimental: + Davies(2138); x Kruithof(2237); Δ Willis(5241).
Theoretical: • Golant(881); ⊙ Heylen(1440).

FIGURE 7.3. α/N, E/N for argon.



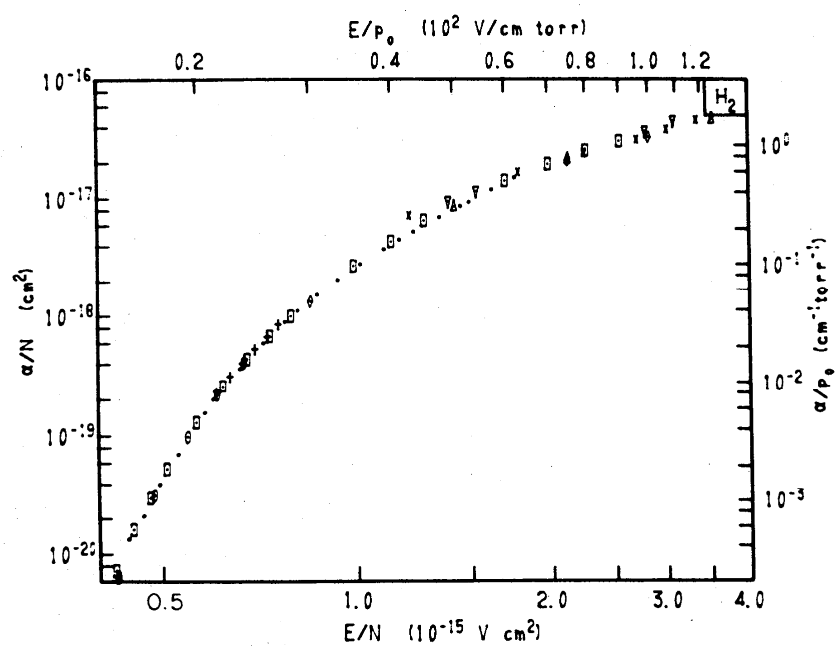
Experimental: ⊙ Kr, + Xe Kruithof(2237); • Kr Heylen(5293).

FIGURE 7.4. α/N, E/N for krypton and xenon.



Experimental: + Chanin(751); ⊙ Blevin(790); ∇ Fletcher(1160); Δ Barna(1174); · Hopwood(1640); x Frommhold(2154); ⊡ Rose(1356).

FIGURE 7.5(a). α/N, E/N for hydrogen for $E/N \leq 3.4\times10^{-15}$ V cm².



Experimental: + Crompton(782); ⊙ DeBitetto(1145); ⊡ Rose(1356); ∇ Haydon(2148); x Jones(2150); Δ Folkard(4907); ϕ Blasberg(5105).
Theoretical: · Engelhardt(260).

FIGURE 7.5(b). α/N, E/N for hydrogen for $E/N \leq 3.4\times10^{-15}$ V cm².

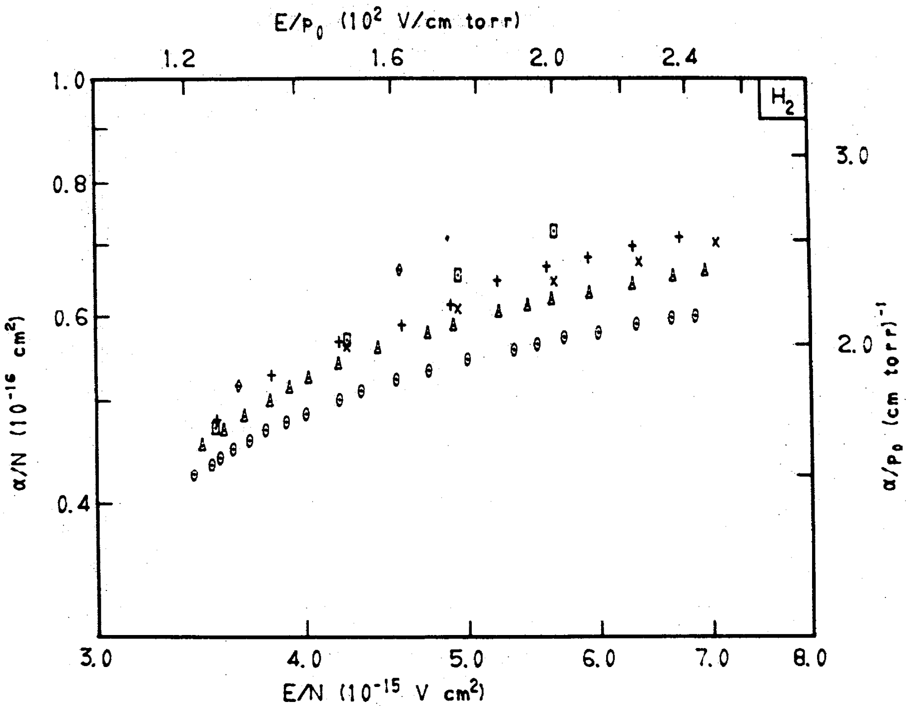


FIGURE 7.6(a). α/N, E/N for hydrogen for $E/N > 3.4\times10^{-15}$ V cm^2.

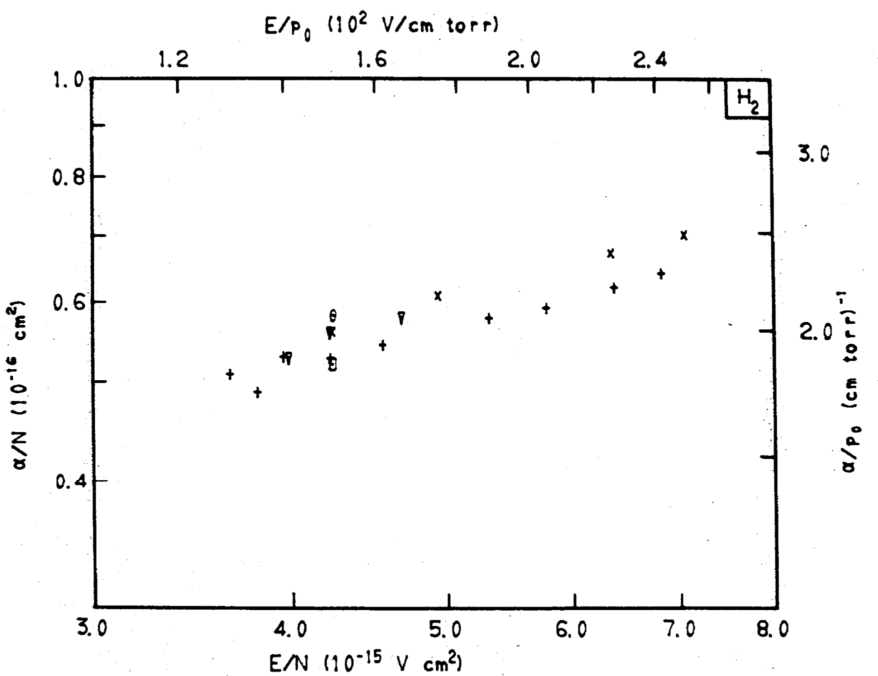


FIGURE 7.6(b). α/N, E/N for hydrogen for $E/N > 3.4\times10^{-15}$ V cm^2.

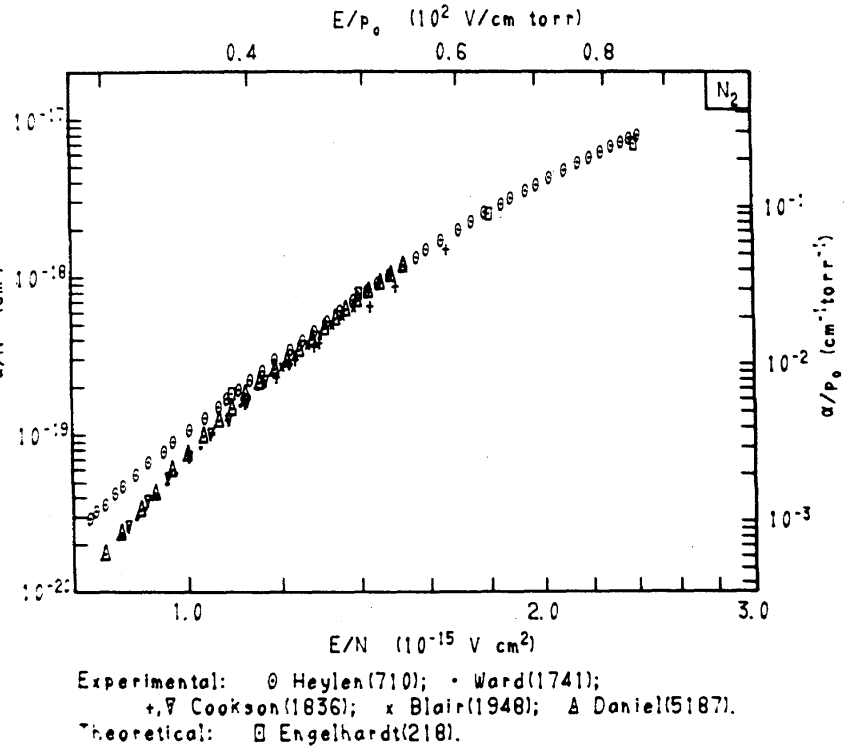


FIGURE 7.7(a). α/N, E/N for nitrogen for $E/N < 2.82 \times 10^{-15}$ V cm^2.

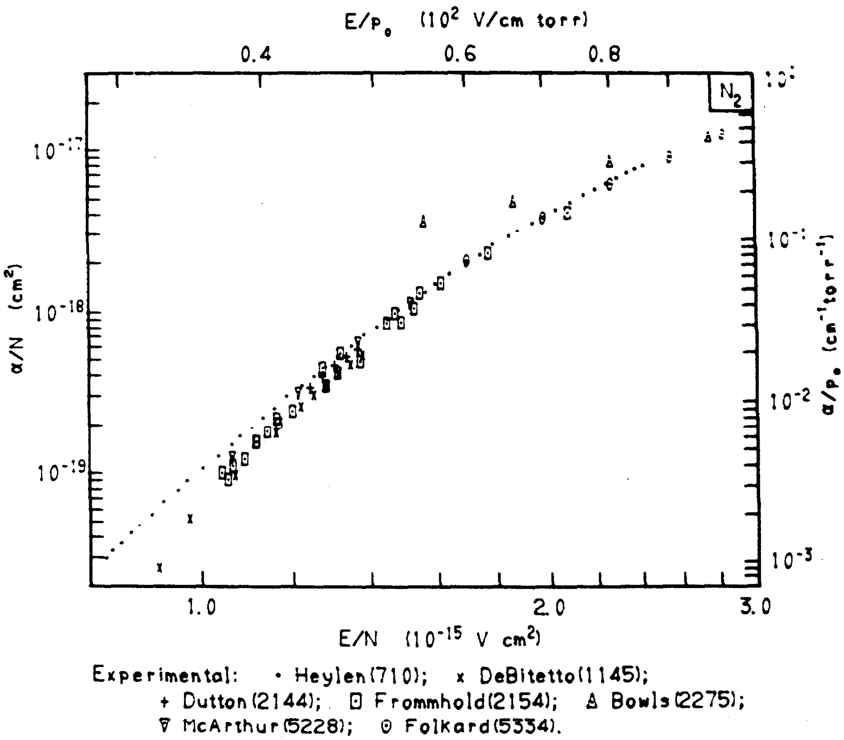
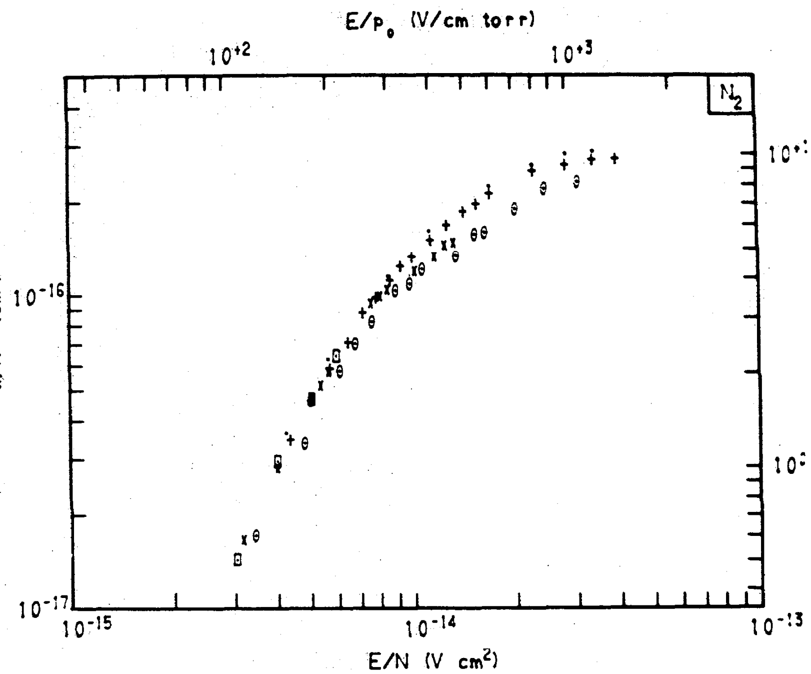
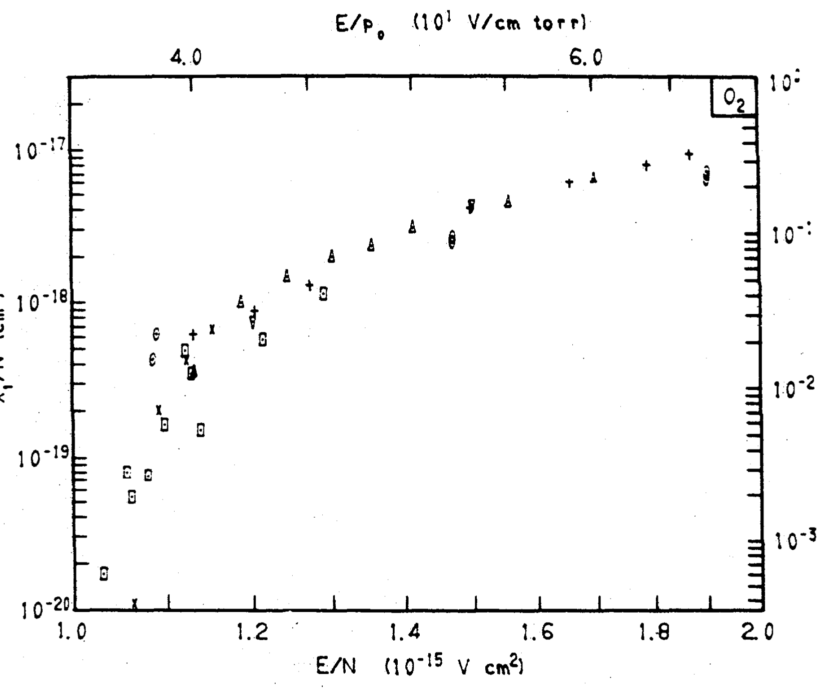


FIGURE 7.7(b). α/N, E/N for nitrogen for $E/N < 2.82 \times 10^{-15}$ V cm^2. (The data of McArthur [5228] were obtained using the expression $\alpha/p_{20} = 6.36 \exp(-257\ p_{20}/E)$ which is stated in the paper to fit the results to within ± 3 percent.)



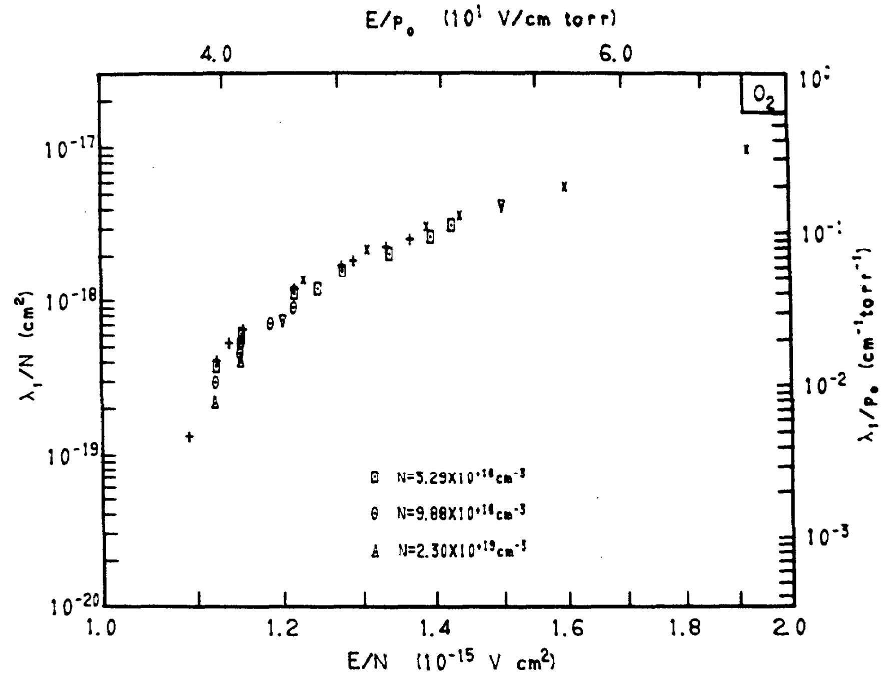
Experimental: ⊖ Bowls(2275); + Bagnall(2448);
x Jones(3297); • Folkard(5334).
Theoretical: ⊡ Engelhardt(218).

FIGURE 7.8. α/N, E/N for nitrogen for $E/N > 2.82\times10^{-15}$ V cm².



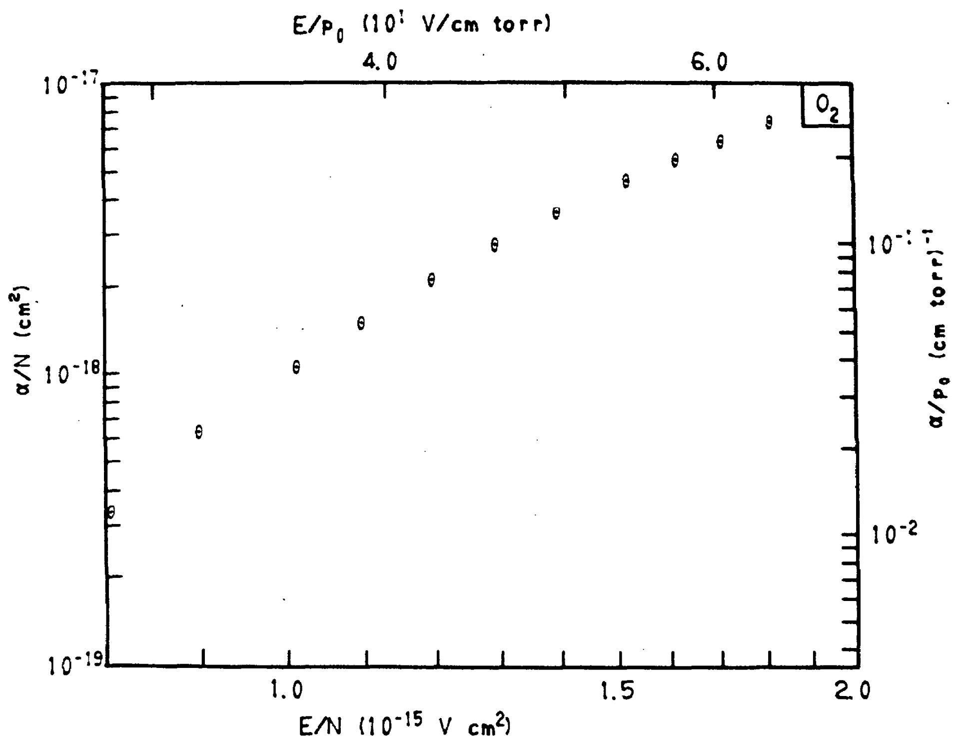
Experimental: x Dutton(573); + Harrison(791);
Δ Freely(961); ⊖ Frommhold(2154); ⊡ Prasad(2555).
Theoretical: ∇ Hake(2553).

FIGURE 7.9(a). λ_1/N, E/N for oxygen for $E/N < 200\times10^{-17}$ V cm².



Experimental: + Prasad(861); x Schlumbohm(2387); □,Θ,Δ Dutton(2908).
Theoretical: ∇ Hake(2553).

FIGURE 7.9(b). λ_1/N, E/N for oxygen for $E/N < 200 \times 10^{-17}$ V cm².



Experimental: Price(4994).

FIGURE 7.9(c). α/N, E/N for oxygen.

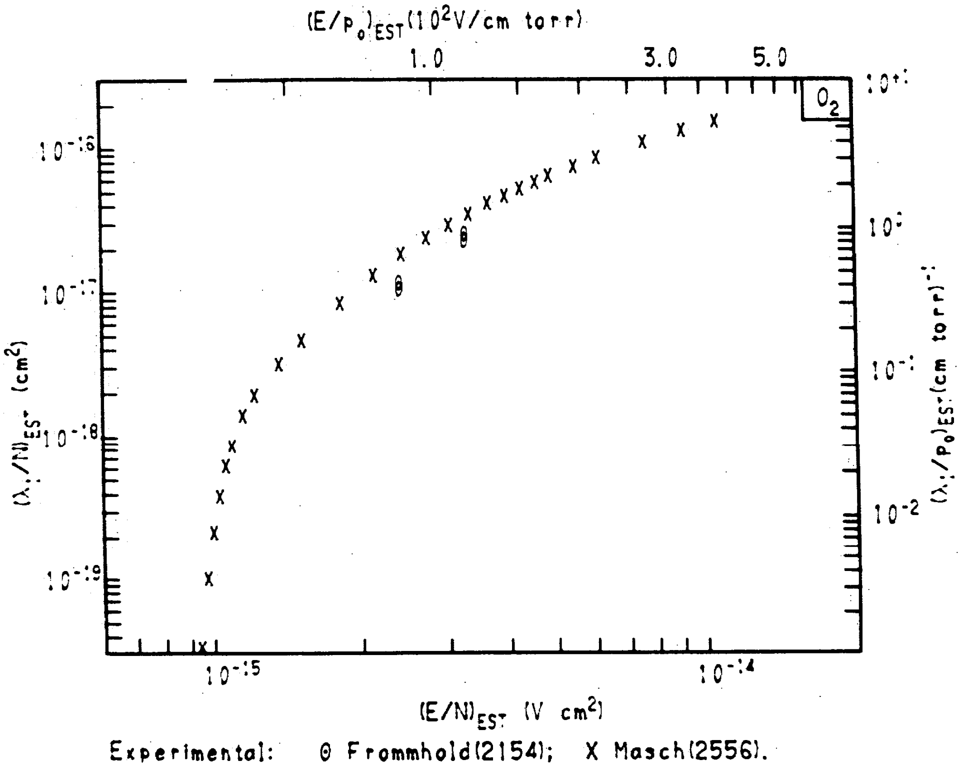


FIGURE 7.10. $(\lambda_1/N)_{Est}$, $(E/N)_{Est}$ for mercury-contaminated oxygen including the region of $E/N > 200 \times 10^{-17}$ V cm². The two results of Frommhold [2154] are for λ_1/N for oxygen uncontaminated with mercury vapor.

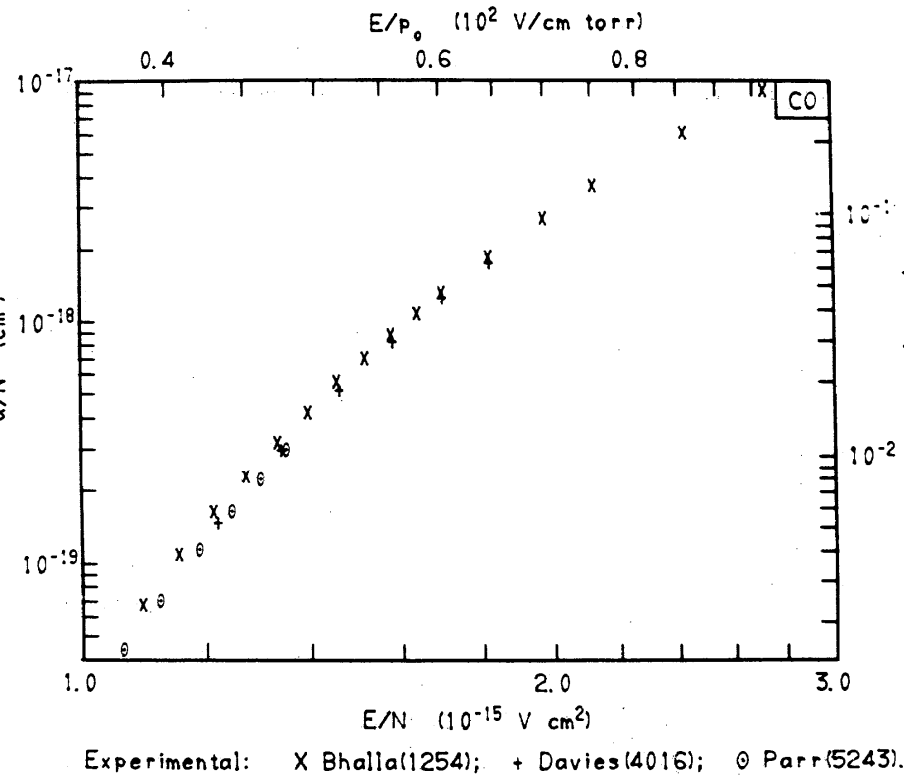
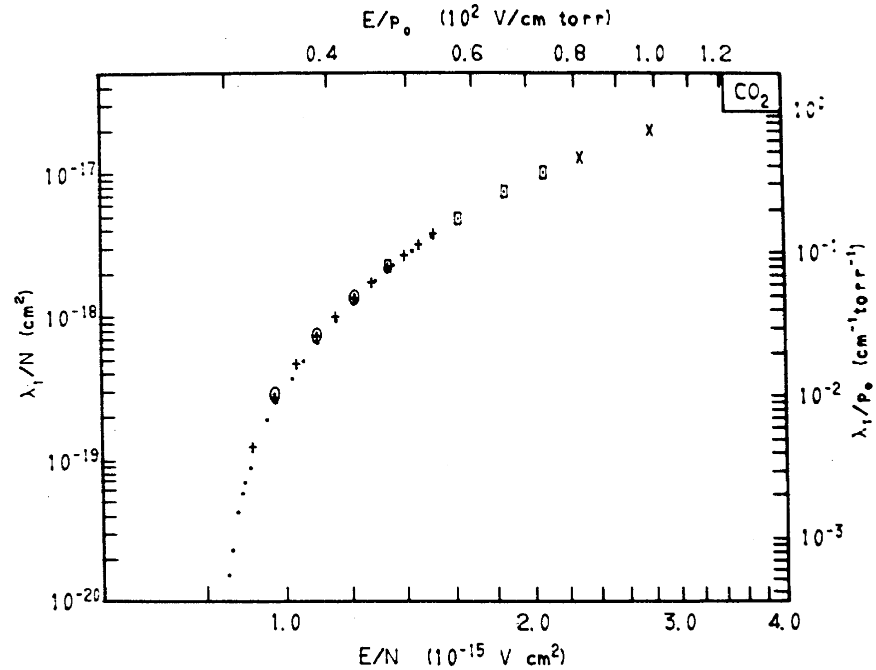
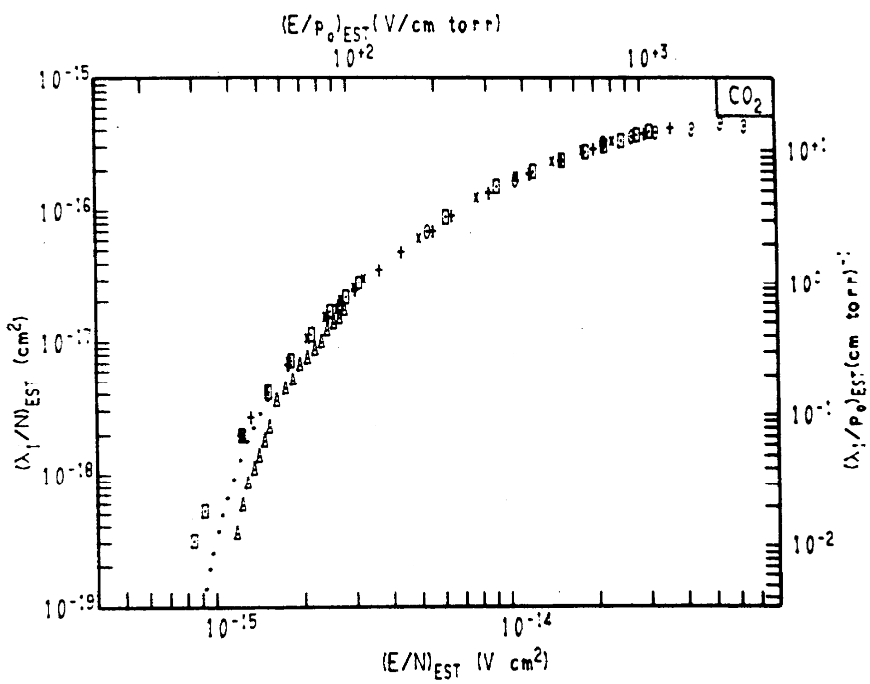


FIGURE 7.11. α/N, E/N for carbon monoxide for $E/N < 300 \times 10^{-17}$ V cm².



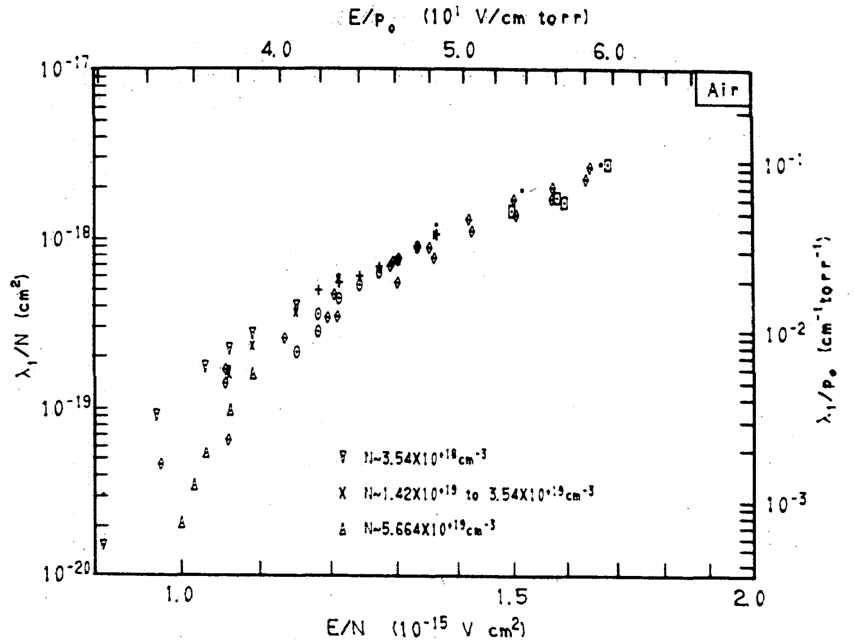
Experimental: + Bhalla(948); ⊡ Schlumbohm(1724);
⊙ Conti(3435); X Schlumbohm(1625).
Theoretical: • Hake(2553).

FIGURE 7.12. λ_1/N, E/N for carbon dioxide for values of E/N up to 300×10^{-17} V cm^2.



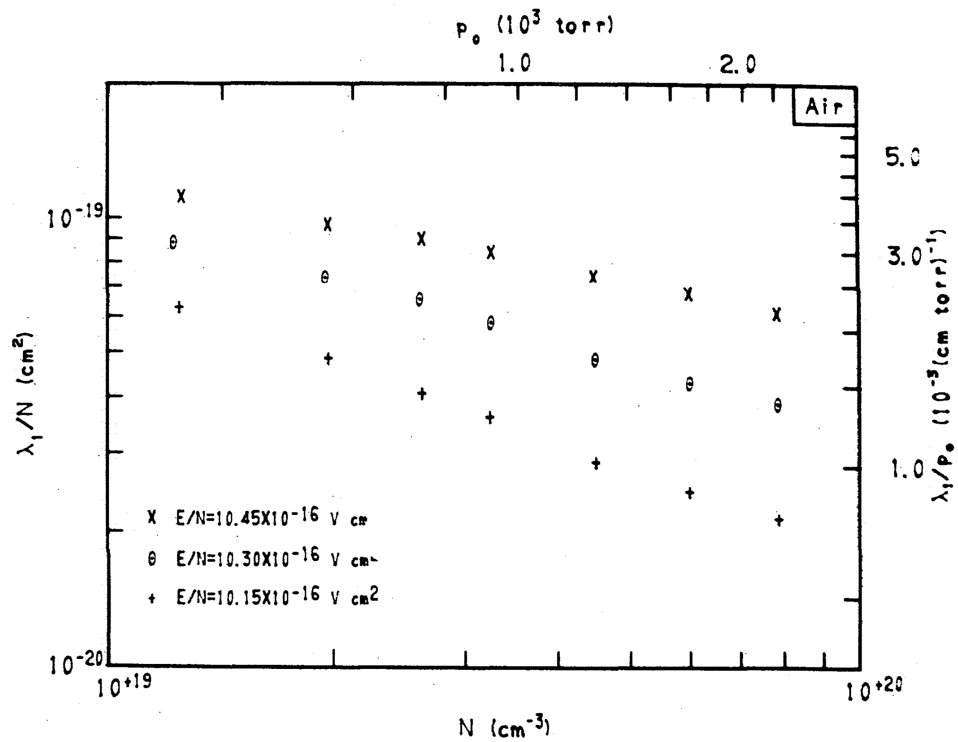
Experimental: + Townsend(2271); x Townsend(2593);
⊙ Hurst(2815); Δ Bishop(3490); ⊡ Bhalla(948).
Theoretical: • Hake(2553).

FIGURE 7.13. $(\lambda_1/N)_{Est}$, $(E/N)_{Est}$ for carbon dioxide for values of E/N up to about 7000×10^{-17} V cm^2.



Experimental: ◇ Harrison(791); · Prasad(2047); + Llewellyn-Jones(2050); ∇ Dutton(2407); x Dutton(2487); ⊖ Hochberg(2558); Δ Dutton(2919); ⊡ Rao(5246).

FIGURE 7.14. (λ_1/N), (E/N) for air for $E/N < 1.7 \times 10^{-15}$ V cm².



Experimental: Daniel(4015)

FIGURE 7.15. Variation of λ_1/N with N at given values of E/N for air.

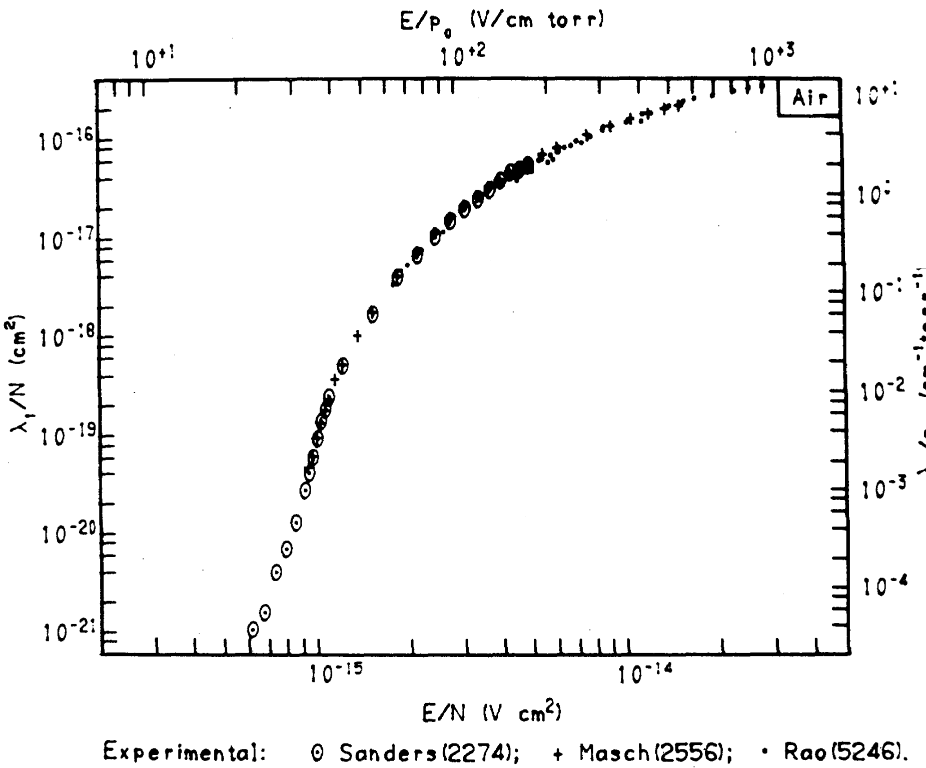


FIGURE 7.16. (λ_1/N), (E/N) for air for values of E/N up to about 2000×10^{-17} V cm². (The results of Sanders [2274] and Masch [2556] are for mercury-contaminated air while those of Rao [5246] are for mercury-free, dry air.)

Table 7.1

Values of α/N for helium

E/N (10^{-17}Vcm²)	α/N (10^{-18}cm²)	E/N (10^{-17}Vcm²)	α/N (10^{-18}cm²)	E/N (10^{-17}Vcm²)	α/N (10^{-18}cm²)
9.09	0.00212 (1)	42.5	3.10 (a)	156.1	18.4 (b)
12.12	0.0303 (1)	42.6	2.67 (b)	170.1	19.2 (b)
15.16	0.127 (1)	56.1	5.1 (a)	184.2	22.3 (b)
17.34	0.277 (b)	57.1	4.0 (b)	196.2	25.7 (a)
19.87	0.48 (b)	71.2	5.9 (b)	198.3	22.8 (b)
19.95	0.43 (a)	85.1	9.4 (a)	226.5	29.2 (b)
23.12	0.79 (b)	85.3	7.4 (b)	254.7	34 (b)
26.01	1.05 (b)	99.3	9.6 (b)	282.8	37 (b)
27.97	1.41 (a)	113.8	12.1 (b)	288.2	37 (a)
28.54	1.39 (b)	127.9	14.8 (b)	420	50 (a)
35.8	2.26 (b)	140.9	17.5 (a)	563	56 (a)
		142.0	16.7 (b)	832	67 (a)

Experimental:
(a) Chanin, et al., Phys. Rev. 133, A1005 (1964).
(b) Davies, et al., Proc. Phys. Soc. (London) 80, 898 (1962).
Theoretical:
(1) Dunlop, Nature 164, 452 (1949).

Table 7.2

Values of α/N for neon

E/N (10^{-17} Vcm^2)	α/N (10^{-18} cm^2)	E/N (10^{-17} Vcm^2)	α/N (10^{-18} cm^2)	E/N (10^{-17} Vcm^2)	α/N (10^{-18} cm^2)
5.65	0.0141 (a)	39.6	2.87 (b)	127.1	17.8 (b)
	0.0184 (b)		2.74 (d)	141.2	19.2 (a)
6.22	0.0223 (b)	42.4	3.2 (a)		20.2 (b)
7.06	0.032 (b)	45.0	4.0 (c)		21.2 (d)
7.91	0.044 (b)	45.2	3.7 (b)	155.4	24.0 (d)
8.48	0.044 (a)	50.9	4.5 (b)	169.5	24.9 (b)
9.04	0.065 (b)		5.1 (d)		26.3 (d)
10.17	0.090 (b)	52.2	5.1 (c)	197.7	29.1 (a)
11.30	0.119 (b)	55.1	5.9 (d)		29.3 (b)
12.71	0.167 (b)	56.5	5.6 (a)		30.8 (d)
			5.4 (b)		
14.12	0.205 (a)			226.0	34 (b)
	0.226 (b)	59.6	6.0 (c)	254.2	38 (b)
15.54	0.294 (b)	62.2	6.4 (b)	282.5	43 (a)
16.95	0.38 (b)		6.8 (d)		42 (b)
19.77	0.55 (a)	65.0	7.3 (d)	339	50 (b)
	0.58 (b)	67.2	7.2 (c)		
				396	56 (b)
22.29	0.88 (c)	70.6	7.8 (b)	424	61 (a)
22.60	0.82 (b)	74.2	8.3 (c)	452	63 (b)
24.01	1.05 (d)	79.1	9.3 (b)	509	69 (b)
24.86	1.32 (c)		9.3 (d)	565	74 (a)
25.42	1.10 (b)	81.4	9.5 (c)		73 (b)
28.01	1.57 (c)	90.0	10.6 (c)	678	82 (b)
28.25	1.31 (a)	90.4	11.2 (b)	791	89 (b)
	1.42 (b)		11.3 (d)	848	102 (a)
	1.53 (d)	101.7	13.3 (b)	904	93 (b)
31.1	1.76 (b)		13.3 (d)	1017	98 (b)
31.7	2.19 (c)	101.8	12.7 (c)	1130	116 (a)
33.9	2.11 (b)	113.0	15.3 (b)		101 (b)
	2.12 (d)	113.3	13.8 (c)		
37.9	2.94 (c)	118.6	15.8 (d)		

Experimental:

(a) Chanin, et al., Phys. Rev. 132, 2547 (1963).
(b) Kruithof, et al., Physica 4, 430 (1937).
(c) Dutton, et al., J. Phys. B: Atom. Molec. Phys. 2, 890 (1969).
(d) Willis, et al., Brit. J. Appl. Phys. (J. Phys. D) 1, 1219 (1968)

Table 7.3

Values of α/N for argon

E/N (10^{-17}Vcm^2)	α/N (10^{-17}cm^2)	E/N (10^{-17}Vcm^2)	α/N (10^{-17}cm^2)	E/N (10^{-17}Vcm^2)	α/N (10^{-17}cm^2)
14.12	0.00068	79.1	0.53	565	12.5
15.54	0.00104	90.4	0.74	678	14.9
16.95	0.00158	101.7	0.95	791	17.0
19.77	0.0032	113.0	1.22	904	19.0
22.60	0.0059	127.1	1.55	1017	20.7
25.42	0.0098	141.2	1.90	1130	22.3
28.25	0.016	169.5	2.62	1271	24.0
31.1	0.025	197.7	3.35	1412	25.6
33.9	0.036	226.0	4.1	1695	28.3
39.6	0.068	254.2	4.8	1977	30.5
45.2	0.109	282.5	5.6	2260	32
50.9	0.158	339	7.0	2542	34
56.5	0.216	396	8.5	2825	35
62.2	0.282	452	9.8	3390	36
70.6	0.40	509	11.2	3960	38
				4520	39

Experimental:
All data taken from Kruithof, Physica 7, 519 (1940).

Table 7.4(a)

Values of α/N for krypton

E/N (10^{-17}Vcm^2)	α/N (10^{-17}cm^2)	E/N (10^{-17}Vcm^2)	α/N (10^{-17}cm^2)	E/N (10^{-17}Vcm^2)	α/N (10^{-17}cm^2)
14.12	0.00044 (a)	62.4	0.233 (b)	226.0	4.2 (a)
15.54	0.00068 (a)	68.4	0.282 (b)	246.1	4.8 (b)
16.95	0.00103 (a)		0.316 (b)	249.7	4.7 (b)
19.77	0.00218 (a)	70.6	0.38 (a)	254.2	4.9 (a)
22.60	0.0041 (a)	77.2	0.38 (b)	282.5	5.7 (a)
25.42	0.0071 (a)	78.3	0.45 (b)	339	7.4 (a)
27.51	0.0046 (b)	79.1	0.51 (a)	396	9.0 (a)
28.25	0.0117 (a)	87.1	0.56 (b)	452	10.6 (a)
30.5	0.0118 (b)		0.59 (b)	509	12.2 (a)
30.8	0.0114 (b)	90.4	0.71 (a)	565	13.7 (a)
31.1	0.0182 (a)	99.0	0.79 (b)	678	16.4 (a)
33.7	0.0173 (b)	101.7	0.93 (a)	791	18.9 (a)
33.9	0.0268 (a)	110.9	1.08 (b)	904	21.2 (a)
	0.0197 (b)	113.0	1.18 (a)	1017	23.3 (a)
36.4	0.0261 (b)	124.2	1.42 (b)	1130	25.3 (a)
36.9	0.030 (b)	127.1	1.51 (a)	1271	27.4 (a)
39.6	0.052 (a)	130.6	1.48 (b)	1412	29.5 (a)
42.3	0.046 (b)	139.2	1.78 (b)	1695	33 (a)
43.1	0.064 (b)	140.2	1.71 (b)	1977	36 (a)
45.2	0.089 (a)	141.2	1.87 (a)	2260	38 (a)
49.4	0.087 (b)	157.1	2.22 (b)	2542	40 (a)
50.9	0.137 (a)	166.4	2.39 (b)	2825	41 (a)
54.9	0.135 (b)	169.5	2.62 (a)	3390	44 (a)
56.5	0.195 (a)	193.2	3.2 (b)	4000	45 (a)
61.5	0.198 (b)	197.7	3.4 (a)	4520	46 (a)
62.2	0.262 (a)	203.1	3.4 (b)	5090	47 (a)
				5650	47 (a)

Experimental:
(a) Kruithof, Physica 7, 519 (1940).
(b) Heylen, Int. J. Electron. 31, 19 (1971).

Table 7.4(b)

Values of α/N for xenon

E/N (10^{-17} Vcm^2)	α/N (10^{-17} cm^2)	E/N (10^{-17} Vcm^2)	α/N (10^{-17} cm^2)	E/N (10^{-17} Vcm^2)	α/N (10^{-17} cm^2)
22.60	0.00054	127.1	0.96	1017	26.7
25.42	0.00102	141.2	1.25	1130	29.4
28.25	0.00181	169.5	1.88	1271	33
31.1	0.0030	197.7	2.60	1412	35
33.9	0.0048	226.0	3.4	1695	41
39.6	0.0109	254.2	4.2	1977	45
45.2	0.0215	282.5	5.1	2260	49
50.9	0.038	339	6.8	2542	53
56.5	0.062	396	8.5	2825	56
62.2	0.092	452	10.3	3390	61
70.6	0.151	509	12.1	4000	65
79.1	0.227	565	14.0	4520	68
90.4	0.36	678	17.5	5090	70
101.7	0.51	791	20.8	5650	72
113.0	0.70	904	23.9	6780	74

Experimental:
All data taken from Kruithof, Physica 7, 519 (1940).

Table 7.5

Values of α/N for hydrogen

E/N (10^{-17} Vcm^2)	α/N (10^{-18} cm^2)	E/N (10^{-17} Vcm^2)	α/N (10^{-18} cm^2)	E/N (10^{-17} Vcm^2)	α/N (10^{-18} cm^2)
42.4	0.0073 (a)	62.0	0.255 (d)	79.0	0.98 (d)
42.7	0.0063 (b)	62.2	0.260 (a)	79.1	1.01 (a)
45.2	0.0161 (a)	62.5	0.282 (e)	84.1	1.37 (e)
45.8	0.0142 (c)	63.7	0.32 (g)	84.7	1.33 (m)
47.9	0.0254 (d)		0.30 (c)	84.8	1.40 (a)
48.0	0.0299 (a)	64.0	0.31 (b)		1.44 (f)
48.7	0.031 (b)	66.7	0.40 (g)	85.1	1.45 (c)
48.8	0.033 (c)	67.0	0.42 (b)	89.0	1.68 (e)
50.9	0.054 (a)	67.8	0.44 (a)	90.6	1.84 (d)
51.8	0.059 (c)	68.0	0.43 (d)	95.7	2.34 (d)
53.7	0.089 (d)	68.4	0.47 (c)	97.2	2.49 (c)
54.8	0.099 (b)	68.9	0.47 (e)	97.3	2.39 (e)
55.2	0.103 (c)	69.6	0.52 (c)	98.9	2.71 (a)
56.4	0.115 (e)	69.7	0.53 (g)	101.4	2.94 (d)
56.5	0.116 (f)	72.8	0.67 (g)	107.0	3.6 (d)
	0.130 (a)	73.2	0.67 (d)	109.1	3.9 (c)
56.6	0.134 (d)	73.5	0.68 (a)	113.0	4.4 (a)
57.9	0.150 (c)	75.8	0.85 (g)	120.4	7.1 (h)
60.6	0.227 (g)	76.0	0.84 (c)	121.0	5.8 (c)
60.9	0.221 (b)	78.7	0.99 (e)	124.5	5.5 (d)
61.1	0.215 (c)			127.1	6.6 (a)

Table 7.5 (continued)

Values of α/N for hydrogen

E/N (10^{-17} Vcm^2)	α/N (10^{-18} cm^2)	E/N (10^{-17} Vcm^2)	α/N (10^{-18} cm^2)	E/N (10^{-17} Vcm^2)	α/N (10^{-18} cm^2)
138.3	9.1 (i)	211.9	22.0 (ℓ)	282.5	36 (a)
140.9	8.3 (d)		20.9 (m)		36 (f)
141.2	8.8 (f)	214.6	22.1 (j)		36 (ℓ)
	8.9 (a)	215.4	25.5 (k)		33 (m)
	8.8 (ℓ)	221.8	26.1 (k)	300	39 (k)
	8.3 (m)				39 (h)
		224.3	24.0 (h)		
152.7	10.41 (j)	226.0	25.1 (a)	306	41 (j)
152.9	11.22 (i)	228.0	25.4 (d)	308	44 (i)
154.0	15.5 (k)	232.3	28.2 (k)	311	41 (k)
162.4	16.6 (k)	240.8	29.8 (k)	321	42 (k)
169.5	13.5 (d)			334	46 (h)
	14.1 (a)	244.0	29.2 (j)		
		247.2	31 (k)	338	45 (k)
173.0	18.2 (k)	254.2	31 (a)	353	48 (ℓ)
177.9	16.7 (h)	257.0	32 (d)	424	57 (ℓ)
181.5	19.5 (k)	264.1	34 (k)		52 (m)
183.7	15.4 (j)			494	61 (ℓ)
187.9	20.7 (k)	270.7	31 (h)		
		272.6	35 (k)	565	65 (ℓ)
196.6	19.4 (d)	274.9	36 (j)		66 (m)
197.7	19.5 (a)	279.1	36 (i)	636	68 (ℓ)
204.8	23.6 (k)			706	71 (ℓ)
208.6	22.2 (d)			847	82 (m)

Experimental:

(a) Rose, Phys. Rev. 104, 273 (1956).
(b) DeBitetto, et al., Phys. Rev. 104, 1213 (1956).
(c) Hopwood, et al., Proc. Roy. Soc. (London) Ser. A 235, 334 (1956).
(d) Barna, et al., J. Appl. Phys. 35, 2781 (1964).
(e) Frommhold, Z. Physik 160, 554 (1960).
(f) Chanin, et al., Phys. Rev. 132, 2547 (1963).
(g) Crompton, et al., Proc. Phys. Soc. (London) Ser. B 69, 2 (1956).
(h) Jones, et al., Proc. Phys. Soc. (London) 72, 363 (1958).
(i) Haydon, et al., Proc. Phys. Soc. (London) 78, 92 (1961).
(j) Blevin, et al., Nature 179, 38 (1957).
(k) Fletcher, et al., in Proc. of the Sixth International Conference on Ionization Phenomena in Gases, Paris, 8-13 July, 1963, (P. Hubert and E. Cremieu-Alcan, Eds., Serma, Paris, 1963), Vol. 2, p. 217.
(ℓ) Folkard, et al., Austr. J. Phys. 24, 527 (1971).
(m) Blasberg, et al., Physica 54, 468 (1971).

Table 7.b

Values of α/N for nitrogen

E/N $(10^{-17} Vcm^2)$	α/N $(10^{-18} cm^2)$	E/N $(10^{-17} Vcm^2)$	α/N $(10^{-18} cm^2)$	E/N $(10^{-17} Vcm^2)$	α/N $(10^{-18} cm^2)$
85.0	0.0181 (a)	121.2	0.31 (f)	165.8	1.50 (c)
87.5	0.0222 (b)	121.4	0.31 (a)	169.5	2.06 (j)
87.7	0.0242 (a)	122.1	0.258 (d)	169.7	2.00 (i)
88.7	0.0252 (b)		0.281 (c)	174.3	2.26 (i)
88.9	0.026 (c)	123.3	0.32 (g)	177.1	2.29 (e)
90.4	0.0293 (b)	123.5	0.299 (c)	179.0	2.60 (i)
91.2	0.034 (a)	124.3	0.33 (h)	184.7	2.93 (i)
91.5	0.0254 (d)	124.4	0.35 (a)	188.2	3.2 (i)
91.9	0.034 (b)	125.3	0.30 (d)	193.6	3.5 (i)
92.2	0.038 (c)	126.4	0.37 (g)	197.5	3.8 (i)
93.8	0.044 (a)	127.3	0.39 (h)	197.7	3.8 (j)
93.9	0.041 (b)		0.44 (e)	202.9	4.3 (i)
96.0	0.049 (b)	127.4	0.42 (a)	207.6	4.2 (e)
96.2	0.053 (c)	128.1	0.36 (c)	208.6	4.8 (i)
97.0	0.061 (a)	128.3	0.35 (d)	214.3	5.3 (i)
			0.34 (e)		
97.5	0.053 (d)			219.3	5.7 (i)
97.7	0.057 (b)	129.2	0.38 (c)	223.3	6.2 (i)
99.9	0.077 (a)	129.4	0.43 (g)	226.0	9.0 (j)
100.2	0.070 (b)	130.3	0.45 (h)	228.9	6.7 (i)
100.3	0.072 (c)	130.4	0.49 (a)	233.2	7.2 (i)
103.0	0.101 (a)	131.1	0.42 (e)	237.1	7.6 (i)
104.1	0.101 (e)	131.3	0.41 (d)	240.7	8.0 (i)
104.5	0.101 (c)	131.9	0.55 (e)	254.2	9.1 (j)
105.2	0.102 (b)	132.5	0.50 (g)	282.5	12.7 (j)
105.3	0.091 (e)	133.4	0.52 (h)	316	16.5 (k)
106.1	0.124 (f)	133.5	0.56 (a)	342	17.1 (ℓ)
106.2	0.126 (a)	134.6	0.47 (d)	400	28.0 (k)
106.3	0.111 (e)	135.5	0.57 (g)	424	36 (j)
106.8	0.097 (d)	136.3	0.64 (a)	436	34 (m)
108.0	0.125 (b)	136.4	0.58 (h)	483	34.2 (ℓ)
			0.64 (f)		
108.3	0.125 (c)			499	46 (m)
108.9	0.123 (e)	137.2	0.49 (e)	507	47 (k)
109.0	0.151 (a)	137.7	0.54 (d)	536	52 (k)
110.9	0.153 (b)	138.4	0.64 (g)	565	63 (j)
111.4	0.156 (e)	139.3	0.73 (a)	567	57 (k)
111.7	0.159 (c)	142.5	0.84 (a)	573	58 (m)
111.9	0.187 (a)	142.9	0.65 (c)	612	57 (ℓ)
112.4	0.164 (c)	143.3	0.67 (c)	646	70 (m)
113.9	0.182 (e)	144.7	0.86 (e)	681	70 (ℓ)
114.8	0.197 (b)	145.7	0.95 (a)	715	87 (m)
115.0	0.219 (a)	147.0	0.98 (e)	757	94 (k)
115.9	0.178 (d)	148.6	1.06 (a)	760	82 (ℓ)
116.2	0.221 (e)	149.0	0.87 (e)	783	98 (m)
116.4	0.207 (e)	150.1	0.87 (c)	804	99 (k)
116.5	0.217 (c)	151.6	1.13 (f)	843	104 (k)
118.3	0.242 (b)	152.4	1.22 (a)	848	114 (j)
118.7	0.267 (a)	152.8	1.06 (e)	857	111 (m)
118.9	0.230 (c)	154.6	1.31 (e)	893	103 (ℓ)
120.0	0.245 (e)	161.2	1.52 (e)	920	123 (m)
120.3	0.269 (g)	164.0	1.72 (i)	983	108 (ℓ)

Table 7.6 (continued)

Values of α/N for nitrogen

E/N (10^{-17}Vcm^2)	α/N (10^{-18}cm^2)		E/N (10^{-17}Vcm^2)	α/N (10^{-18}cm^2)		E/N (10^{-17}Vcm^2)	α/N (10^{-18}cm^2)	
999	131	(m)	1326	148	(k)	2255	248	(m)
1017	119	(k)	1336	133	(ℓ)	2260	260	(j)
1070	120	(ℓ)	1414	185	(m)	2441	220	(ℓ)
1130	160	(j)	1530	157	(ℓ)	2812	260	(m)
1135	149	(m)	1550	195	(m)	2825	282	(j)
1159	132	(k)	1635	159	(ℓ)	3050	231	(ℓ)
1243	145	(k)	1692	211	(m)	3370	268	(m)
1267	167	(m)	1695	223	(j)	3390	288	(j)
			2013	189	(ℓ)	3930	270	(m)

Experimental:

(a) Daniel, et al., J. Phys. B 3, 363 (1970).
(b) Ward, Nature 208, 994 (1965).
(c) Cookson, et al., Brit. J. Appl. Phys. 17, 891 (1966).
(d) DeBitetto, et al., Phys. Rev. 104, 1213 (1956).
(e) Frommhold, Z. Physik 160, 554 (1960).
(f) McArthur, et al., 1st Int. Conf. Gas Discharges, London, 284 (1970).
(g) Blair, Brit. J. Appl. Phys. 17, 1051 (1966).
(h) Dutton, et al., Proc. Roy. Soc. (London) Ser. A 213, 203 (1952).
(i) Heylen, Nature 183, 1545 (1959).
(j) Folkard, et al., J. Phys. B 6, 214 (1973).
(k) Jones, Brit. J. Appl. Phys. (J. Phys. D) 1, 769 (1968).
(ℓ) Bowls, Phys. Rev. 53, 293 (1938).
(m) Bagnall, et al., Austr. J. Phys. 18, 227 (1965).

Table 7.7

Values of α/N for carbon monoxide

E/N $(10^{-17}Vcm^2)$	α/N $(10^{-18}cm^2)$	E/N $(10^{-17}Vcm^2)$	α/N $(10^{-18}cm^2)$	E/N $(10^{-17}Vcm^2)$	α/N $(10^{-18}cm^2)$
106.1	0.044 (c)	130.0	0.225 (c)	158.0	0.82 (b)
109.1	0.067 (a)	133.4	0.32 (a)	163.7	1.08 (a)
112.1	0.070 (c)	134.0	0.294 (b)	169.7	1.31 (a)
115.2	0.109 (a)	135.1	0.299 (c)	170.0	1.24 (b)
118.8	0.114 (c)	139.4	0.42 (a)	181.9	1.87 (a)
121.2	0.164 (a)	145.5	0.56 (a)	182.0	1.76 (b)
122.0	0.145 (b)	146.0	0.52 (b)	197.0	2.70 (a)
124.6	0.165 (c)	151.6	0.71 (a)	212.2	3.7 (a)
127.3	230 (a)	157.6	0.89 (a)	242.5	6.1 (a)
				272.8	9.2 (a)

Experimental:
- (a) Bhalla, et al., Proc. Phys. Soc. (London) 78, 438 (1961).
- (b) Davies, et al., in Contributed Papers of the Ninth International Conference on Phenomena in Ionized Gases, Bucharest, 1-6 Sept. 1969, (Academy of the Socialist Republic of Romania, 3 Bis Gutenberg Ave., Bucharest, 1969), p. 46.
- (c) Parr, et al., 10th Int. Conf. Phen. Ion. Gas. (1971), p. 8.

Table 7.8

Values of λ_1/N for carbon dioxide

E/N $(10^{-17}Vcm^2)$	λ_1/N $(10^{-18}cm^2)$	E/N $(10^{-17}Vcm^2)$	λ_1/N $(10^{-18}cm^2)$	E/N $(10^{-17}Vcm^2)$	λ_1/N $(10^{-18}cm^2)$
90.9	0.121 (a)	169.8	6.7 (a)	858	135 (e)
97.0	0.268 (a)	185.2	7.4 (c)	1140	181 (a)
	0.289 (b)	199.1	10.6 (a)	1188	190 (e)
103.1	0.47 (a)	206.7	10.2 (c)	1426	222 (a)
109.1	0.73 (a)	229.1	12.9 (d)	1518	236 (e)
	0.75 (b)	229.6	15.7 (a)	1714	258 (a)
115.2	1.00 (a)	260.0	20.3 (a)	1961	290 (e)
121.2	1.34 (a)	279.1	20.0 (d)	1991	285 (a)
	1.36 (b)	287.7	26.1 (a)	2275	310 (a)
127.3	1.72 (a)	298.6	24.2 (e)	2576	340 (a)
133.4	2.17 (a)	363	36. (e)	2825	360 (a)
133.5	2.25 (c)	430	49. (e)	2919	370 (e)
139.4	2.64 (a)	552	70. (e)	3580	420 (e)
145.5	3.2 (a)	570	83.8 (a)	4240	410 (f)
151.6	3.7 (a)	642	92 (e)	5300	460 (f)
162.3	4.8 (c)	857	141 (a)	6370	430 (f)

Experimental:
- (a) Bhalla, et al., Proc. Phys. Soc. (London) 76, 369 (1960).
- (b) Conti, et al., in Contributed Papers of the Eighth International Conference on Phenomena in Ionized Gases, Vienna, 27 Aug.-2 Sept. 1967 (Springer-Verlag, Vienna, 1967), p. 23.
- (c) Schlumbohm, Z. Physik 166, 192 (1962).
- (d) Schlumbohm, Z. Physik 184, 492 (1965).
- (e) Townsend, Phil. Mag. 3, 557 (1902).
- (f) Hurst, Phil. Mag. 11, 535 (1906).

Table 7.9

Values of λ_1/N for air for $E/N > 140 \times 10^{-17}Vcm^2$

E/N ($10^{-17}Vcm^2$)	λ_1/N ($10^{-18}cm^2$)		E/N ($10^{-17}Vcm^2$)	λ_1/N ($10^{-18}cm^2$)		E/N ($10^{-17}Vcm^2$)	λ_1/N ($10^{-18}cm^2$)	
141	1.57	(b)	311	22.8	(b)	565	73.5	(c)
141	1.61	(c)	311	24.0	(c)	566	57.1	(a)
150	1.47	(a)	316	19.7	(a)	579	68.7	(a)
160	1.64	(a)	333	23.2	(a)	589	61.9	(a)
168	2.76	(a)	336	25.2	(a)	612	72.8	(a)
170	3.59	(b)	339	28.5	(b)	612	80.9	(a)
170	3.67	(c)	339	29.7	(c)	643	81.5	(a)
176	3.30	(a)	341	24.4	(a)	675	83.6	(a)
182	3.94	(a)	355	27.9	(a)	701	94.4	(a)
188	4.52	(a)	367	34.9	(b)	706	98.9	(c)
191	4.04	(a)	367	34.8	(c)	731	90.0	(a)
197	5.36	(a)	378	32.4	(a)	780	105	(a)
198	6.33	(b)	379	28.0	(a)	847	123	(c)
198	6.64	(c)	395	41.7	(b)	859	121	(a)
205	5.19	(a)	395	39.6	(c)	865	131	(a)
210	6.67	(a)	397	31.6	(a)	915	135	(a)
217	7.23	(a)	404	34.5	(a)	989	144	(c)
222	7.64	(a)	420	39.6	(a)	1020	148	(a)
226	9.61	(b)	424	45.3	(b)	1130	164	(c)
226	10.3	(c)	424	45.2	(c)	1150	150	(a)
233	8.57	(a)	427	36.0	(a)	1160	178	(a)
240	10.1	(a)	427	41.9	(a)	1230	181	(a)
254	10.6	(a)	441	44.8	(a)	1270	184	(c)
254	13.9	(b)	448	37.4	(a)	1410	198	(c)
254	14.4	(c)	452	49.7	(b)	1410	215	(c)
261	11.6	(a)	452	51.7	(c)	1550	216	(a)
260	12.4	(a)	474	49.3	(a)	1570	237	(a)
269	13.9	(a)	476	47.3	(a)	1700	252	(a)
275	15.0	(a)	489	52.6	(a)	1950	270	(a)
282	16.5	(a)	490	49.3	(a)	2280	279	(a)
282	18.0	(a)	497	54.0	(a)	2550	318	(a)
282	19.2	(a)	501	46.7	(a)	2830	333	(a)
296	16.3	(a)	508	63.6	(c)			
296	18.8	(a)	530	59.4	(a)			
310	21.0	(a)	538	62.4	(a)			

Experimental:
- (a) Rao, et al., J. Phys. D 4, 494 (1971).
- (b) Sanders, Phys. Rev. 44, 1020 (1933).
- (c) Masch, Arch. Elektrotech. 26, 587 (1932).

3.8. Recombination Coefficient

When both electrons and positive ions are present in a gas there is a finite probability that should an ion and electron come close to one another they will recombine to form a neutral atom or molecule. This process is different from all the others considered in this survey in that it involves the interaction of two charged particles rather than a charged and a neutral particle. Thus, although it is a process that can occur in electron avalanches, recombination is usually of greater importance in the study of more highly ionized gases where the probability of collision between electrons and ions is greater. In certain circumstances, e.g. in a highly ionized high-density plasma, it can be the dominant mechanism by which charged particles are removed from the gas.

When an electron and an ion recombine, the energy of the system after collision is less than that before, and the difference has to be dissipated in some way. As in the case of electron attachment, the various possible recombination processes are designated by the way in which the excess energy is removed. Thus, radiative recombination may be represented by

$$e + X^{+} \rightarrow X + h\nu \qquad (18)$$

dielectronic recombination by

$$e + X^{+} \rightarrow X'' \rightarrow X' + h\nu \qquad (19)$$

dissociative recombination by

$$e + XY^{+} \rightarrow X + Y + \text{k.e.} \qquad (20)$$

and three-body recombination by

$$e + X^{+} + Z \rightarrow X + Z + \text{k.e.} \qquad (21a)$$

or by

$$e + X^{+} + e \rightarrow X + e + \text{k.e.} \qquad (21b)$$

In these equations e represents an electron, $h\nu$ a quantum of radiation, X, Y, and Z neutral atoms, X′ and X″ singly and doubly excited electronic states of a neutral atom and k.e. indicates that the energy difference of the reaction is removed as kinetic energy of the particles concerned.

In a gas in which there exists a number density n of electrons and N_+ of positive ions, the rate of removal of the charged particle by the process denoted by eqs (18), (19), or (20) is given by

$$\frac{dn}{dt} = \frac{dN_+}{dt} = -r_2 n N_+, \qquad (22)$$

where r_2 is a constant, called the two-body recombination (rate) coefficient. From eq (22) it can be seen that r_2 has the units of cm^3s^{-1}.

The rate of removal of charged particles by three-body recombination is given by

$$\frac{dn}{dt} = \frac{dN_+}{dt} = -r_3 n N_+ N, \qquad (23a)$$

or

$$\frac{dn}{dt} = \frac{dN_+}{dt} = -r_3 n^2 N, \qquad (23b)$$

depending on whether the effective third body is an atom or an electron. In this case r_3 is the three-body recombination coefficient having units of cm^6s^{-1}.

The values of the recombination coefficient are usually determined experimentally by measuring the decay of concentration of electrons with time for conditions in which recombination is the dominant loss mechanism. There are, however, numerous difficulties in the interpretation of the experimental data obtained.

First, diffusion always provides a competing mechanism for the decay of electron concentration and considerable care is needed to establish that the dominant loss mechanism is that of recombination [2169] (see also E. P. Gray and D. E. Kerr, Ann. Phys. (New York) **17**, 276, 1962) or to make corrections for the loss by diffusion [see, e.g., 3443].

Second, there is often more than one ion species present in the ionized gas, so that the measured decay rate depends on a number of different recombination processes proceeding at different rates. Thus, additional measurements of the rate of decrease of concentration of the ion species involved are most useful, but have only been carried out in a few recent experiments. Additional evidence from spectroscopic measurements can also be helpful in determining the processes occurring.

Third, even in a plasma decaying in a field-free region there are sometimes processes occurring which can give rise to the production of electrons which compete with the loss processes and must be taken into account. In helium, for example, the production of electrons in collisions between two 2^3S metastable atoms has an appreciable rate coefficient which can significantly affect the net rate of decay of electrons in an afterglow (A. W. Johnson and J. B. Gerardo, Phys. Rev. A **7**, 925, 1973).

Finally, at very low densities radiative recombination becomes the only significant recombination process and at very high densities collisional recombination is dominant; but for intermediate densities, both processes occur. In these circumstances the recombination is not simply the sum of the various processes because, as shown by Bates, Kingston, and McWhirter [444], the processes are coupled. Under these circumstances, three-body recombination occurs to excited states, together with transitions between the bound states both by radiative and collisional processes and between the bound states and the continuum by collision processes. The term collisional radiative recombination is then used to describe the processes occurring. Although the processes themselves are complex, the experimental results are usually expressed as an equivalent two-body decay coefficient g.

The collisional radiative decay coefficient g_c can be expressed for optically thin plasmas in terms of a collisional radiative recombination coefficient r_c and a collisional radiative ionization coefficient i_c by the relationship

$$g_c = r_c - i_c(N/N_+), \quad (24)$$

both r_c and i_c depending only on n and on the electron temperature T_e.

In general, the recombination coefficient depends on the temperature and density of the electrons, of the ions, and of the neutral gas particles, these temperatures and densities often themselves being interrelated. Graphs of r as a function of n and of r/n as a function of T_e can be a useful way of presenting data for comparison purposes if the other parameters of the experiments are similar. Probably the most satisfactory way of presenting the results, however, is in tablular form, when values of all the relevant parameters (if known) can be included.

3.8.a. Recombination Coefficient—Helium

There have been more than 30 experimental investigations of recombination in helium but most of them fall conveniently into two groups, viz.—those carried out at relatively high electron concentrations ($>10^{11}$ cm^{-3}) mostly at low gas pressures (~ m Torr), and those at lower electron concentrations ($<10^{11}$cm^{-3}) mostly at high gas pressures ($\gtrsim 10$ Torr).

(i) *High electron concentrations.* The results obtained in a number of experimental investigations of the recombination coefficient at high electron concentrations are shown in figure 8.1. These experimental results are compared with values computed theoretically by Bates and Kingston [2168] for quasi-equilibrium plasmas on the basis of the theory of collisional radiative recombination in which the three-body recombination process is

$$e + He^+ + e \rightarrow He + e.$$

The results over the full range for which these computations have been made are given in table 8.1, but the theoretical values shown in figure 8.1 refer to a gas number density of 10^{14} cm^{-3} which is about the middle of the range used in the various experiments; the curves labelled (a) and (b) in this figure correspond respectively to plasmas which are optically thin and optically thick to the resonance lines. In the conditions under consideration, the decay coefficient may be equated to the collisional radiative recombination coefficient, except for a correction for Penning ionization in the case of optically thick plasmas and this has been shown to be small [3381] except at low temperatures and high densities.

All the experimental results shown in figure 8.1 were obtained for static afterglows but for a wide range of conditions. Magnetic confinement was used in some [1639, 2331, 2447] but not in others [883, 1870, 1961, 3658] and the gas number densities ranged from about 8.8×10^{12} to 2.5×10^{15} cm^{-3}. Other factors such as the size of the containing vessel may also have an influence, so that although there is considerable spread in the values obtained, the general agreement between theory and experiment supports the view that in this region collisional radiative recombination is the dominant decay process.

Numerical data corresponding to the experimental results on static afterglows shown in figure 8.1 are given in table 8.2, together with another set of data, obtained by Born [3464], for a range of gas temperatures at each value of n. These results were also shown to be consistent with the theory of collisional radiative recombination when the elevated gas and electron temperatures are taken into account. Values obtained from the study of plasma jets [759], which are appreciably different, are also included in this table.

Measurements on the early stages of afterglows have also been made by Chen [5745] to give r as a function of n and of T_e. These results are included in figure 8.2 where they are compared (i) with the other experimental results from table 8.2 for which T_e is available, and (ii) with the theoretically computed values of Bates and Kingston [2168] and of Mansbach and Kech [5761]. The latter were obtained using Monte Carlo trajectory methods and may be represented by the equation

$$r/n = 2\times10^{-27}(kT_e)^{-9/2},$$

with kT_e in electron volts. It can be seen that this expression gives a curve lying below and with a slightly smaller slope than a curve drawn through the majority of the experimental points. Recombination rates deduced from some spectroscopic observations [5327] of decaying afterglows appear to be in better agreement with those obtained from the theoretical computations of Mansbach and Kech than from those of Bates and Kingston.

Calculations of the collisional radiative recombination coefficient r_c as functions of n and T_e as independent variables have been made by Drawin and Emard [5732] and by Chen [5745]. The former used a method which is similar to that of Bates et al. but which did not assume hydrogenic energy levels. The latter used a simplified method based on the existence of a minimum in the total rate of de-excitation of atoms as a function of the energy level of the excited states. Results using this method are compared in figure 8.3 with the data for an optically thin plasma by Drawin and Emard.

The complete range of Drawin and Emard's data for both optically thin and optically thick plasmas is given in table 8.3. (Results for other assumed conditions are also given in their paper.)

The influence of the neutral particle density on the collisional radiative recombination coefficient through the reaction

$$He^+ + e + He \rightarrow He + He,$$

has also been investigated [1259, 5130, 5773, 5774, 3653]. The results for conditions in which $T_e = T_g$ and T_e is 250 and 300 K [1259, 5773, 5774] are shown in figure 8.4 and tabulated in table 8.4(a), together with theoretical values [1259, 5130] for higher values of $T_e = T_g$. As pointed out in [5130] the values at low electron densities are much higher than those calculated in [1259] for $n \rightarrow 0$, because even low densities of electrons are efficient in transporting excited electrons through the system of energy levels. In tables 8.4(b), (c), and (d) values of r as a function of N obtained [5773] with $T_g = 300$ K but different values of $T_e > T_g$ are given.

Measurements were made by Chen [4586] of rate of decay of the density of electrons and of atomic and molecular ions in an afterglow as a function of electron and atom temperatures for initial electron densities in the range 10^{12} to 3×10^{14} cm^{-3}. Analysis of these results, taking into account processes of formation of molecular ions and the recombination of both atomic and molecular species but not the production of electrons in metastable collisions (see section 3.8.a(ii)) lead to electron temperature dependence of the dissociative recombination coefficient r_2 of the form

$$r_2 = 1.9 \times 10^{-5} (T_e)^{-1.48} \text{ for } N = 6 \times 10^{16} \text{ cm}^{-3} \text{ and } T_g = 410 \text{ K}$$

and

$$r_2 = 8.9 \times 10^{-9} (T_e)^{-0.36} \text{ for } N = 6 \times 10^{16} \text{ cm}^{-3} \text{ and } T_g = 1250 \text{ K}.$$

(ii) *Low electron concentrations.* Experimental investigations of recombination at low electron concentrations involve the use of high gas pressures (~ 15 Torr) in order to reduce the influence of diffusion. The high pressure favors the formation of He_2^+ ions by the reactions

$$He^+ + 2He(1^1S) \rightarrow He_2^+ + He(1^1S)$$

$$2He(2^3S) + He(1^1S) \rightarrow He_2^+ + e + He(1^1S)$$

so that more than one recombination process is possible. Moreover, in some of the experiments, the results were found to depend on the way in which the plasma was produced initially, and in some the range of electron densities over which n^{-1} was found to be linearly dependent on t was not great enough (see E. P. Gray and D. E. Kerr, Ann. Phys. (New York) **17**, 276, 1959), to be an adequate test of the assumption that the decay was recombination dominated, an assumption necessary to obtain the values quoted. These difficulties account, at least in part, for the fact that a wide range of values from 6×10^{-10} to 6.8×10^{-8} cm^{3}s^{-1} have been obtained for the effective recombination coefficient r_e.

The value of the effective recombination coefficient (~ 10^{-8}cm^{3}s^{-1}) obtained from early measurements [249, 596, 802, 1642] was much higher than that for radiative recombination which is about 4.8×10^{-12}cm^{3}s^{-1} at 250 K, decreasing to 4.31×10^{-13} and 2.69×10^{-13}cm^{3}s^{-1} at 10,000 and 20,000 K, respectively [715]. The relatively high experimental values led to the suggestion that the dominant recombination process was dissociative recombination of the He_2^+ ion and experimental results showing r_e to be independent of electron density [2456] and of gas pressure [249, 2456] lent support to this view.

A review of the available data on recombination coefficients and spectroscopic measurements in the light of theoretical considerations of dissociative and collisional radiative recombination by E. E. Ferguson, F. C. Fehsenfeld, and A. L. Schmeltekopf, (Phys. Rev. **138**, A381, 1965), however, led to the conclusion that the experimetal results up to that time could be interpreted more satisfactorily on the basis of collisional radiative recombination. This seemed to be further confirmed by a subsequent experimental investigation by Berlande et al. [4374] which showed that the decay rate in carefully purified helium depended on both the electron concentration and the gas density. The results obtained over the ranges $10^9 < n < 5 \times 10^{11}$cm^{-3} and $3.5 \times 10^{17} < N < 3.5 \times 10^{18}$cm^{-3} could be represented by an effective recombination coefficient r_e given by

$$r_e = r_2 + kn + K'N$$

with $r_2 \simeq 5 \times 10^{-10}$cm^{3}s^{-1}, $k = (2 \pm 0.7) \times 10^{-20}$cm^{6}s^{-1}, and $K' = (2 \pm 0.5) \times 10^{-27}$cm^{6}s^{-1}.

The above value for k compares with a value of 10×10^{-20} from the theoretical calculations of Bates et al. [444] and of 4×10^{-20} from the theoretical treatment of Deloche [3653]; the above value for K' compares with theoretical values of 2.5×10^{-27} cm^{6}s^{-1} obtained from the work of Pitaevski [2165] and of 1×10^{-27} cm^{6}s^{-1} from the values for the collisional radiative recombination coefficient for the process

$$He^+ + e + He \rightarrow 2He$$

calculated by Bates and Khare, which are given in table 8.4.

The conclusion that the recombination processes involved are collisional radiative recombination of He_2^+ with both electrons and helium atoms acting as third bodies is, however, invalidated by the recent work of Johnson and Gerardo [5570, 5488, 5730]. They have shown that the recombination coefficient determined in all previous work is actually, as already indicated by the above nomenclature, an effective recombination coefficient. The reason is that no previous analysis had taken into account an intense source of free electrons which their measurements on the effect of a heating pulse on the electron and atomic metastable densities in a decaying plasma clearly showed to be present. This source is considered to be ionization in metastable-metastable collisions, and when it is taken into account an actual recombination coefficient is obtained which is as much as five times larger than the effective recombination coefficient. The actual recombination coefficient is given by

$$r = r_2 + KN$$

with $r_2 = 1.1 \times 10^{-8}$ cm^{3}s^{-1} and $K = 1.3 \times 10^{-26}$ cm^{6}s^{-1} in the range $4.8 \times 10^{17} < N < 18 \times 10^{17}$ cm^{-3}. This work has also shown [5325] that under the conditions of the experiments dissociative recombination accounts for a large fraction of the total recombination.

The situation is, however, still not completely clarified, because although the results of Johnson and Gerardo [5570] for the effective recombination coefficient r_e range from about 3.4×10^{-9} cm^{3}s^{-1} at 15 Torr to about 6.5×10^{-9} cm^{3}s^{-1} at 65 Torr, in good agreement with the results of Berlande et al. [4374] for $n = 10^{11}$ cm^{-3}, they indicate no dependence on electron density in the range $4 \times 10^{10} < n < 5 \times 10^{11}$ cm^{-3}, being more in accord in this respect with other recent work [5772] in which the effective recombination coefficient at $N \sim 1.4 \times 10^{18}$ cm^{-3} showed only a weak dependence on electron density for $10^{10} < n < 10^{12}$ cm^{-3}. Moreover, using a theoretical analysis which included a source term for the production of electrons during the afterglow, but an experimental tube of much smaller diameter than the above workers, Boulmer et al. [5343] obtained values of the recombination coefficient which showed no variation with N for $7 \times 10^{17} < N < 11 \times 10^{17}$ cm^{-3}. The values and their variation with temperature agree with those calculated by Mansbach and Kech [5761] on the basis of collisional radiative recombination.

At low temperatures where the dominant ion is He_3^+ there have been two recent investigations [5203, 5134] which show that the recombination coefficient is much higher than that at room temperature, the values of the effective recombination coefficient being $(3.4 \pm 1.4) \times 10^{-6}$ cm^{3}s^{-1} for $T_g = T_e = 80$ K [5203] and $(5 \pm 0.75) \times 10^{-6}$ for $T_g = 4.2$ K and $T_e = 80$ K [5134]. The dependence on electron temperature in both cases was found to be of the form $T_e^{-\gamma}$ with γ somewhere within the range 0.8 to 1.6.

3.8.b. Recombination Coefficient—Neon

Most of the published data for recombination in neon have been obtained for relatively low electron densities ($< 10^{11}$ cm^{-3}) from measurements of plasma decay using microwave techniques. It can be seen from the results given in table 8.5 that when $T_e = T_+ = T_g = 300$ K, there is good agreement between the values obtained by a number of observers, especially if the appropriate corrections [see Frommhold, Biondi, and Mehr 3443] are made for diffusion and for the initial distribution of electrons in the plasma.

A number of observers [673, 1363, 2988] have shown that the recombination coefficient is independent of pressure indicating that the dominant recombination process is a two-body process. The suggestion [966] that, because of the relatively high value of the coefficient, this two-body process is dissociative recombination of electrons with Ne_2^+ ions has been confirmed experimentally by using a mass spectrometer to observe the decay of the Ne_2^+ ions simultaneously with that of the electrons [2988, 4044] and also by spectroscopic observations [1600].

The results of recent measurements [2988, 3443, 4044, 4585] on the temperature dependence of the recombination coefficient are shown in figure 8.5 and given in table 8.6. It can be seen that in contrast to the results of some earlier measurements [1363] in which no temperature dependence was apparent, the recombination coefficient varies as $T_e^{-\gamma}$ over the range 300 K $< T_e <$ 11,000 K.

When the electron temperature alone was increased by microwave heating the value of γ was found by Biondi et al. [3443, 4044] to be 0.43 over the whole range and by Hess [584] to be 0.4 in the range $900 < T_e < 2400$ K, but 0.25 in the range $300 < T < 900$ K.

When the electron, ion, and gas temperatures were all varied together over the range 295 to 503 K by heating the cavity, Kasner [2988] obtained a value of 0.42 for γ. Other experiments [4585] in which the gas was heated by means of a shock wave led to a similar value of γ for temperatures below 700 K but to a value of 1.5 for temperatures in the range from 700 to 3500 K. This change in value of γ at high temperatures can be satisfactorily accounted for theoretically (T. F. O'Malley, Phys. Rev. **185**, 101, 1969) if the recombination coefficient decreases rapidly for recombination to vibrationally excited states of the molecular ion. The experimental results of Chen [4586], at higher electron densities in plasmas produced by a condenser discharge, however, indicate no variation of the dissociative recombination coefficient with T_g in the range 420 to 1500 K for constant values of $T_e = 300$ K.

Experimental measurements of the decay of electron density and of electron temperature in a decaying condenser discharge in which the electron density was about 5×10^{12} cm^{-3} led [5745] to much lower values of r than discussed above. These values are given in figure 8.6, where, bearing in mind the measured values of n and T_e, they can be seen to be consistent with the values calculated [5745] on the basis of collisional radiative recombination theory using the approximate method mentioned in section 3.8.a(i); these theoretical values are estimated in the original paper to be accurate within a factor of 4. A low value for r of 5.3×10^{-14} cm^3 s^{-1} was also obtained [5775], at an even higher value of $n \sim 5 \times 10^{17}$ cm^{-3} but unmeasured temperature, from observations of the H_α and H_β lines from a decaying plasma in a small admixture of hydrogen in neon.

3.8.c. Recombination Coefficient—Argon

Measurements of the recombination coefficient for argon have been carried out at both relatively high and low electron densities and it is convenient to consider them in two groups corresponding to values of n greater and less than about 10^{11} cm^{-3}.

(i) *Large values of* $n(>10^{11}$ *cm*$^{-3})$. Recombination coefficients at high electron concentrations have been measured for quasi-equilibrium plasmas in argon by a variety of techniques [1961, 3433, 3468, 5240, 5745, 5775, 5776, 5777, 5782] over a range of n up to about 10^{17} cm^{-3} and over a range of gas number densities from about 1.7×10^{16} cm^{-3} to 10^{20} cm^{-3}. In some of the measurements [1961, 3468, 5745] both n and T_e were determined but in most, either T_e or n was measured and equilibrium assumed. The results are shown as a graph of r, n in figure 8.7.

Also shown in this figure are the theoretical results obtained [1961, 5745] on the basis of collisional radiative recombination theory for the same values of n and T_e as those measured experimentally [1961, 5745]. The full range of the values calculated in [5201] and [5745] are shown in figure 8.8; r is given as a function of n at various values of T_e.

Some of the results obtained from a study of the radiation from a plasma jet [5782] at atmospheric pressure are also included in figure 8.7. For clarity of presentation, the data shown were chosen from the large number of values given so as to cover the range of parameters investigated. All the experimental results were found to fit the empirical equation

$$r = 1.28 \times 10^5 \times T^{-1.8} \times 10^{-(3410/T)} \times n^{-0.64}.$$

Theoretical values for the same range of parameters were also obtained in this study [5782] on the basis of both collisional radiative and dissociative recombination. The results are shown in figure 8.7, from which it can be seen that better agreement is obtained between theoretical and experimental results of this particular study on the assumption of dissociative recombination rather than collisional radiative recombination.

(ii) *Low values of* $n\,(<10^{11}$ *cm*$^{-3})$. Although there have been a number of investigations [673, 711, 758, 811, 1363, 1642, 4065] of the recombination coefficient at relatively low values of n for values of $N \geq 3.5 \times 10^{17}$ cm^{-3} for $T_e = T_g = T_+ = 300$ K, the value of r is not as well established as that for neon, values ranging from 2×10^{-7} to 1.1×10^{-6} cm^3 s^{-1} having been obtained. Bearing in mind difficulties with gas purity [1363] and with variation of r with the power of the exciting discharge [711, 1642, 2186] and the range of values of electron density over which measurements were made in a given experiment, the most reliable values seem likely to be those in [673], [758], and [4065] which are given in table 8.7.

There have been no simultaneous observations of the decay of electron and ion densities using a mass spectrometer in argon in this range. Nevertheless, the observation [758] that the value of r for argon is at least a factor of 10^3 greater than that in argon-helium mixtures, together with spectroscopic observations (L. Frommhold and M. A. Biondi, Phys. Rev. **185**, 244, 1969) and mass spectrometer studies (G. E. Veatch and H. J. Oskam, Phys. Rev. A **1**, 1498, 1970) of the ion species formed in argon-helium mixtures, lead to the conclusion that the values of r in table 8.7 refer definitely to dissociative recombination of Ar_2^+ ions with electrons.

Investigations of the temperature dependence of the recombination coefficient in the range from room temperature up to a few thousand degrees Kelvin show similar results to those in neon, although the agreement between the absolute values obtained by various observers at slightly elevated temperatures is not as good as that in neon. As can be seen from figure 8.9 and table 8.8, the values of r vary as $T^{-\gamma}$ for the temperature ranges covered, but the value of γ depends on the method of heating used. When microwave heating was used [4065] to raise T_e to values in the range 300 to 10,000 K, while T_g and T_+ remained at 300 K, γ was found to be 0.67. When, on the other hand, a shock wave was used [1873, 3438, 4585] to give conditions in which $T_e = T_+ = T_g = T$, a similar value of γ was found for $T < 670$ K but γ became 1.5 for $670 < T < 3500$ K. (Probe measurements [5184] in the Faraday dark space of a glow discharge gave a value for r of 1.2×10^{-8} at $T_e \simeq 14{,}000$ K which lies between the extrapolation of the two curves in figure 8.9.)

The above change in value of γ can be explained (T. F. O'Malley, Phys. Rev. **185**, 101, 1969) if it is assumed that the coefficient representing recombination to vibrational states of the molecular ion decreases rapidly as the vibrational level increases. Whether such a decrease occurs depends on the details of the potential energy curves of the particular molecular ion and of the state of the neutral molecule formed initially [4586, 4065]. No information on the change of r_2 with T_g alone and thus on the change of r_2 with vibrational level is available in the conditions of the above experiments. Observations on the decay of plasmas of higher electron density (n_e in the range 10^{13} to 10^{16} are mentioned for He, but no details given for Ar) produced by a condenser discharge [4586] have, however, been interpreted as showing an increase, rather than a decrease of r_2 with increasing T_g for constant T_e in argon.

3.8.d. Recombination Coefficient—Krypton and Xenon

The only investigation of recombination coefficients in relatively pure samples of krypton (impurity content <2.5 parts in 10^5) at room temperature, was that carried out by Oskam and Mittelstadt [673]; results are given in table 8.9.

Other investigations of afterglows in krypton containing xenon [254, 2445] at levels of 0.01 to 0.1 percent and 0.5 percent, respectively, gave electron-density-decay curves which had different slopes in the early and later afterglow. Spectroscopic observations [254] showed that the KrI spectrum predominated in the early afterglow and the XeI spectrum in the late afterglow. The different slopes of the electron-density-decay curves were thus interpreted as being due to recombination with krypton ions in the early afterglow and with xenon ions in the late afterglow. Analysis of the curves on this basis led to values of r for krypton of 6 to 12×10^{-7} cm^3 s^{-1} [254] and not greater than 11×10^{-7} cm^3 s^{-1} [2445], in fair agreement with the more accurate values in table 8.9.

The low value of 3×10^{-7} cm^3 s^{-1} obtained for krypton from probe measurements of the decay of positive ion concentration following a dc discharge in krypton of unspecified purity [3188] is probably accounted for by complications arising from the interpretation of probe measurements in the presence of striations and the low pressure (1.5 Torr) used, at which diffusion is significant.

The variation of the recombination coefficient with temperature was measured [5128] over the range 800 to 2500 K in experiments in which the krypton was heated by means of shock waves so that $T_e = T_+ = T_g$. The results are given in figure 8.10 and in table 8.10, and it can be seen that r shows a $T^{-1.5}$ dependence as in argon over the same temperature range.

At a value of T_e of about 14,000 K, probe measurements in the Faraday dark space of a glow discharge gave a value of 1.4×10^{-8} cm^3 s^{-1} for r.

The situation in xenon is complicated by the fact that the cross section for momentum transfer is relatively large. Thus, at the pressures (≥ 10 Torr) required to make recombination the dominant loss mechanism, the assumption which is usually made (viz., that the collision frequency for momentum transfer is negligible with respect to the frequency of the microwave probing field) leads to measured values of the recombination coefficient, r_m say, which are related to the true values by the expression

$$r_m = [1 + (ap_0)^2] r.$$

In this expression $a = \nu_m/\omega_0$ and ν_m is the momentum transfer collision frequency at a pressure of 1 Torr and ω_0 the resonant frequency of the cavity in the absence of electrons.

The most reliable measurements in xenon are again those of Oskam and Mittelstadt [673], who observed the above predicted pressure dependence for samples of xenon containing less than 1 part in 10^5 krypton and obtained the value of r given in table 8.9 by extrapolating their results to zero pressure. Measurements [860] in samples containing not more than 1 percent krypton gave a similar pressure dependence and led to a value lying between 12 and 16×10^{-7} cm^3 s^{-1} in good agreement with the value in table 8.9. The late afterglow measurements in krypton containing 0.5 percent xenon, mentioned above [254], also gave values of r for xenon in the range 12 to 21×10^{-7} cm^3 s^{-1}. An apparent pressure dependence was also found in other experiments but in one case [2130] it is not clear whether the values given are of r or of r_m and in the other [2445] only values of r_m are given.

There are no published measurements of the temperature dependence of r in Xe nor any mass spectrometer observation of the ion species involved in the plasma decay of Kr or Xe. From the spectroscopic observations [254] and the relatively high value of r however, it is assumed that dissociative recombination of Kr_2^+ and Xe_2^+ is the dominant recombination mechanism.

3.8.e. Recombination Coefficient—Hydrogen

Surprisingly few experimental investigations [239, 240, 2292, 1363, 5500] have been made of recombination coefficients in hydrogen at low electron densities ($< 10^{11}$ cm^{-3}) and there are marked differences between the results obtained. This probably arises from the fact that there are known to be four stable ion species H^+, H_2^+, H_3^+, and H_5^+ and no measurements have been made, to date, in which a mass spectrometer has been used to identify the ions concerned.

At pressures of a few Torr where H_3^+ and H_5^+ ions might be expected to play a significant role, several observers [240, 2292, 5500] have obtained values of r which increase with pressure above 1 Torr. The absolute values obtained for r were, however, very different, ranging, for example, from about 0.12×10^{-6} to 2×10^{-6} cm^3 s^{-1} at about 3 Torr. Moreover, other measurements [1363] gave a pressure-independent value for r of 2.5×10^{-6} cm^3 s^{-1} for $3 < p < 12$ Torr. In one set of experiments [239], r was found to be too low to measure ($< 3 \times 10^{-8}$ cm^3 s^{-1}), the plasma decay being due entirely to diffusion and markedly dependent on very small amounts of impurities. In this case, the value of the ambipolar diffusion coefficient obtained indicated that the ion species being studied was probably H^+. It seems likely that differing experimental conditions, including the purity of the gas samples, power of the exciting discharge, dimensions of the apparatus, and range of electron densities used give rise to different concentrations of the various possible ion species in different experiments, thus altering the plasma decay rate and making ion identification essential if significant values for r are to be obtained.

Theoretical computations of r for H_2^+ using Monte Carlo methods [1665] and perturbation theory [3471] lead to values of 3×10^{-8} cm^3 s^{-1} and 2.5×10^{-8} cm^3 s^{-1}, respectively, at 300 K. The temperature dependence in the latter case is given by $r = 4.2 \times 10^{-8}$ $T^{-1/2}$, with a value which does not exceed 3×10^{-8} cm^3 s^{-1}. These computed values of r for H_2^+ are much lower than the experimental values which again suggests that the measured values refer to H_3^+ and/or H_5^+.

For H^+ ions, theoretical calculations have been made of the radiative recombination coefficient r_2 [601, 1602, 2259, 2390], and of the collisional radiative recombination coefficient r_c [444, 731, 972, 994, 1639, 2147, 3381, 5781] over a wide range of conditions.

The values of the radiative recombination coefficient in table 8.11 are those given by Bates and Dalgarno [4656] based on the results of Seaton [601]. In addition to the total recombination coefficient r_2, the partial radiative recombination coefficients $r_2(p)$ to each level of principal quantum number p are also given over a range of temperatures from 250 to 64,000 K.

Among the first calculations of r_c were those of d'Angelo [731] who developed a method in which he considered the reaction paths of individual electrons, on the basis that the processes occurring were three-body recombination of electrons into excited states, followed either by their transition to lower levels with the emission of radiation or by their ejection into the continuum in collisions with another electron. Collisional transitions between bound states were, however, neglected, so that at relatively low temperatures (~ 1000 K) where such collisions play a significant role, the values of r_c obtained are considerably lower than those calculated with the complete statistical theory of Bates et al. [444]. At relatively high temperatures when radiation processes dominate the two theories give results in good agreement.

The statistical theory, in which the populations of the states were obtained from the governing rate equations, was first developed [444] to calculate values of r_c for optically thin plasmas for a range of values of the electron temperature T_e and density n. These are given in table 8.12, together with the values of the collisional radiative ionization coefficient i_c which enable the collisional radiative decay coefficient g_c to be obtained using eq (24). Also given in table 8.12(a) are values of the collisional radiative recombination coefficient calculated using the general curves given by Bates and Kingston [994] for temperatures < 250 K.

The calculations were later extended [146] to several different cases of optically thick plasmas. Values of r_c for (a) a plasma optically thick towards the lines of the Lyman series, which is likely to correspond to most laboratory plasma, are given in table 8.13(a). The other cases considered were plasmas optically thick (b) to the Lyman continuum as well as to the Lyman series (c) to lines of all series and (d) to lines of all series and the Lyman continuum. The values obtained are given in table 8.13(b), (c) and (d), respectively.

Although these tables give r_c as a function of n and T_e, these are, in practice, not independent variables. Their relation to the values for the collisional radiative recombination coefficient were thus calculated by Bates and Kingston [2147] for two different plasma models. In the first, which corresponds to a magnetically confined plasma, the only energy flow was assumed to be to the boundary from the atom gas, the energy flow from the electron and ion gas being zero. In the second, the energy flow to the boundary from the electron gas was assumed to be zero but that from the ion and atom gas was assumed to be such as to keep both T_i and T_g the same as that of the walls. The results (which are useful for comparison with experiment) are given in tables 8.14 to 8.17 for plasmas that are optically thin and optically thick to lines of the Lyman series.

Experimental results for recombination coefficients obtained for magnetically confined high density ($n > 10^{11}$ cm^{-3}) hydrogen plasmas [1389, 1639, 5778, 5779] are shown in figure 8.11, where they are compared with the theoretical curves for r_c for an optically thick magnetically confined plasma at 250 K obtained from table 8.14.

Taking into account the values of the initial atom density the experimental values of [1639] are in fair agreement with the theoretical curves. The experimental values of [1389] fall below the theoretical values, but the measured values of T_e are also different from those calculated for an optically thick plasma. Taking the measured values of n and T_e into account, the measured values lie between those calculated (using tables 8.12 and 8.13) for optically thin and optically thick plasmas.

The results obtained [5697] from the decay of spark channels lie closer to the calculated values for optically thin plasma as can be seen from figure 8.12.

In addition to the calculations of the collisional radiative recombination coefficients on the basis of the detailed statistical theory discussed above, a number of calculations [595, 640, 972, 1639, 1647, 5327, 5745, 5761, 5781] of the collisional recombination coefficient r_3 (to which r_c tends in the limit of high n) have been made. These calculations were carried out using various simplified models based, for example, on the simple Thomson formula [1614] or on the existence of a critical energy level in the atom, transitions across which determine the net rate of recombination. Several of these treatments [595, 640, 1614, 1639, 1647, 5761, 5781] led to analytical expressions which show that r_3 varies with electron temperature as $T_e^{-9/2}$. The actual values obtained for r_3, which depend on the values used for the collision cross sections, are compared in figure 8.13 with those calculated from the detailed statistical theory [444] in which Gryzinski's cross sections (M. Gryzinski, Phys. Rev. **115**, 374, 1959) were used.

Comparison of some results of spectroscopic observations in helium with the recombination rates predicted by the two methods have led to the suggestion [5327] that Gryzinski's cross sections are too large.

Measured values of the recombination coefficient are also included in figure 8.13 for comparison.

3.8.f. Recombination Coefficient—Nitrogen

As noted above for hydrogen, the simultaneous existence of a number of different ion species in molecular gases at pressures of a few Torr greatly complicates the determination of recombination coefficients in these gases. In nitrogen it is well known that the species N^+, N_2^+, N_3^+ and N_4^+ are all stable and that ion conversion reactions between species occur in collisions with N_2 molecules. Thus, as the pressure, temperature and conditions of excitation in the discharge change, so does the relative concentration of the various ion species. This largely accounts for the very wide range of pressure dependent values of r (from 0.1 to 2×10^{-6} cm^3 s^{-1}) obtained [703, 728, 807, 811, 1363, 2372, 2394] in nitrogen at pressures ranging from 0.1 to 40 Torr.

The only extensive experiments in which the ions have been identified and their decay monitored simultaneously with that of the electrons are those of Biondi and his collaborators [1247, 1344, 1605, 2455, 2993]. In these experiments, the ion species N_2^+ was made the predominant one by carrying out the afterglow experiments in mixtures of neon and nitrogen in which the partial pressure of the neon ranged from 15 to 30 Torr and that of nitrogen from about 10^{-4} to 5×10^{-3} Torr. Two sets of measurements [1247 and 2993] for $T_e=T_i=T_g$=300 K, when the decay of N_2^+ ions was shown experimentally to follow closely the decay of electrons, gave a value for r for N_2^+ ions as $(2.7\pm0.3)\times10^{-7}$ cm^3 s^{-1}, when the appropriate corrections were made for diffusion and the variation of the electron density distribution in the microwave cavity with time.

Measurements by Mahdavi et al. [5124] in a flowing afterglow, in a mixture of N_2 at pressures in the range 10^{-3} to 10^{-2} Torr with Ar at about 0.6 Torr, gave a value of $(2.2\pm0.4)\times10^{-7}$ cm^3 s^{-1} for mass identified N_2^+ ions at 300 K, in good agreement with the above value obtained from static afterglow measurements.

At partial pressures of nitrogen greater than 10^{-2} Torr, in the static afterglow experiments, it was shown that the N_3^+ and N_4^+ ion species became predominant and that above about 0.1 Torr there were more N_4^+ than N_3^+ ions present. The recombination coefficient depended on the conditions, being between 1 and 2×10^{-6} cm^3 s^{-1}, the value increasing as the ratio of N_4^+ to N_3^+ ions became larger. These values are not inconsistent with the pressure dependent value of $r\sim10^{-6}$ cm^3 s^{-1} obtained at the higher pressures (> few Torr) in nitrogen by many observers [703, 807, 2372, 2394, 3166], suggesting that these values as would be expected, also refer to a mixture of N_3^+ and N_4^+ ions.

The concentration of different ion species also depends on the temperature so that to obtain significant results for the variation of recombination coefficient with temperature, it is necessary to determine the ion species involved by mass spectrometer. The results obtained for this variation under these conditions [2993, 4045, 4605, 4681] are shown in figure 8.14, both for the case in which the electron temperature T_e and the gas temperature T_g are varied simultaneously and for the case in which T_e alone is varied.

It can be seen that when both T_e and T_g were varied, r was found to be independent of temperature, whereas when T_e alone was varied r varied as $T^{-0.39}$. In the latter experiment [4045], however, although the predominant ion species was N_2^+ the decay of this species did not follow the electron decay nearly as well as in the earlier work [2993, 1247] and the value of r at room temperature $(1.8^{+0.4}_{-0.2})\times10^{-7}$ cm^3 s^{-1} was considerably lower. The experimental conditions were very similar in all experiments and the discrepancy has not been explained. The two other results [4605, 4681] were obtained using a Langmuir probe, together with a mass spectrometer and do not agree well with those obtained by microwave methods.

Thus the variation of r_2 with temperature for N_2^+ ions is not well established at present.

There have been calculations [750] of the radiative and dielectronic recombination coefficient for atomic nitrogen and of the collisional radiative recombination coefficient for the reaction $Z^++e+N_2\rightarrow Z+N_2$ for ions of mass 28 amu [4604]. The results of these calculations are given in tables 8.18 and 8.19, respectively.

The dissociative recombination coefficient for N_2^+ ions has also been calculated [1675] using a semiclassical method. The value of 2.0×10^{-7} cm^3 s^{-1} so obtained is in surprisingly close agreement with the experimental value of 2.7×10^{-7} cm^3 s^{-1}.

3.8.g. Recombination Coefficient—Oxygen

As in nitrogen and hydrogen, there are a number of stable species of ions in oxygen. Difficulties in the determination of the recombination coefficient arising from this source are, however, not as acute as in the case of nitrogen, because over a wide range of suitable experimental conditions the O_2^+ ion is the dominant species. The situation is, however, complicated by the occurrence of the process of three-body electron attachment to neutral gas molecules to form negative ions. As a result, the electron decay rate at low pressures in oxygen alone is pressure dependent, and measurements are thus usually carried out using a small concentration of O_2 (at a pressure of a few mTorr) in an inert buffer gas at a pressure of a few Torr. This ensures that the decay of electrons by recombination is much greater than that by attachment or by diffusion. To avoid the effects of negative ion accumulation, measurements are usually made in afterglows following single discharge pulses with relatively long delays (~ seconds) between pulses.

The four most recent results [3611, 3786, 4045, 5124] obtained for r_2 for O_2^+ ions at room temperature are in good agreement and are given in table 8.20. In two of these determinations [4045, 3611], the electron decay in a static afterglow was measured using the microwave method. The decay of the O_2^+ ions was also monitored simultaneously using a mass spectrometer and shown to follow closely the electron decay. In another [5124] a floating double probe and ion sampling arrangement were used to measure the decay of electrons and mass identified ions in a flowing afterglow in a mixture of oxygen and argon. Finally in [3786], the electron decay in a static afterglow was measured by a Langmuir probe and although the ion species was not identified, conditions were chosen so that, on the basis of previous experiments in which a mass spectrometer was used, the O_2^+ ion was expected to be the dominant species. As indicated in the table, the buffer gases used were also different in the four experiments. In one of the microwave experiments [4045], r_2 was found to vary with the partial pressure of the oxygen in a mixture of O_2 and Ne. In this mixture the O_2^+ ions were formed by Penning ionization of O_2 in collision with metastable neon atoms and could thus have been in an electronically excited state. The effect of different mixtures was investigated and the dependence of r_2 on the oxygen partial pressure found to be least in the case of the $O_2-Ne-Kr$ mixture. In this case the O_2^+ ions were formed by the Penning ionization of Kr by Ne metastables followed by charge exchange between the Kr^+ and O_2, so that the O_2^+ ions were formed in the ground electronic state and a low vibrational state.

The values given in table 8.20 are also in good agreement with the earlier values of 2.1×10^{-7} and 1.9×10^{-7} $cm^3\ s^{-1}$ obtained by Mentzoni [3428] and by Asimov [1601] respectively, in experiments in which no identification was made of the species concerned. Both of these experiments were carried out in oxygen alone, Asimov et al. using low pressures (5×10^{-2} to 10^{-1} Torr) together with a confining magnetic field to reduce diffusion losses and Mentzoni using higher pressures from 0.15 to 4 Torr. In both cases the quoted value of r_2 was obtained from consideration of the observed variation of r with pressure.

Warke [1675] obtained theoretical values of the dissociative recombination coefficient for O_2^+ at room temperature on the basis of a semiclassical calculation and showed that with certain simplifying assumptions, a quantum treatment would lead to the same results. More detailed quantum calculations on the basis of Warke's approach but using different potential curves, were made by Chan [4020]. The results of both sets of calculations are also shown in table 8.20.

The results of experimental measurements of the temperature dependence of r_2 for O_2^+ are shown in figure 8.15. In one of these investigations [4045] T_e alone was varied, while in others [3611, 3428, and 3786] the temperature of the whole system was varied, thus keeping $T_e=T_i=T_g$. When T_e alone was varied for a mixture of O_2 and Ne, r_2 was found to vary as $T_e^{0.70}$ up to 1200 K and as $T_e^{-0.56}$ between 1200 K and 5000 K. It can be seen from the figure that this variation at the lower temperatures was similar to that obtained by Kasner and Biondi [3611] when T_e, T_i, and T_g where all varied together in an O_2-Ne mixture. On the other hand, where T_e, T_i, and T_g were varied together in O_2-He mixtures [3786] and in pure O_2 [3428], a less marked variation of r with temperature was observed.

The single values at elevated electron temperatures given by Sayers [4605, 4681] were obtained using a Langmuir probe for O_2^+ ions identified using a mass spectrometer.

At temperatures ~200 K, for both $O_2-Ne-Kr$ mixtures [3611] and O_2-He mixtures [3786] relatively high values of the effective recombination coefficient were obtained. Mass spectrometric studies in [3611] showed the existence of substantial quantities of O_4^+ ions under these conditions and the results were analyzed to give a value for r_2 of about 2.3×10^{-6} $cm^3\ s^{-1}$ for O_4^+ ions and of $(3\pm0.3)\times10^{-7}$ $cm^3\ s^{-1}$ for O_2^+. Measurements of the decay of electron concentration by cylindrical Langmuir probes in static afterglows in krypton-oxygen mixtures at 180 K gave values for r_2 of $(1.8\pm0.6)\times10^{-6}$ $cm^3\ s^{-1}$ for O_4^+ and of $(3.5\pm1.0)\times10^{-7}$ $cm^3\ s^{-1}$ for O_2^+ in agreement with the microwave measurements.

The results of theoretical computations of the radiative recombination coefficient [1180] and the dielectronic recombination [750] for O^+ are given in table 8.21 from which it can be seen that the dielectronic coefficient is negligible with respect to the radiative one and that both are much smaller than the dissociative recombination coefficient for O_2^+.

3.8.h. Recombination Coefficient—Carbon Monoxide

The only published value of the recombination coefficient for carbon monoxide at room temperatures is $(6.8\pm1.2)\times10^{-7}$ $cm^3\ s^{-1}$ obtained by Mentzoni and Donohoe [3601]. From an experimental investigation of the decay of a static afterglow using a microwave method, the value obtained was independent of pressure for pressures of 0.55 and 0.92 Torr which, together with the high value of r, suggests that a dissociative recombination process is involved. No ion identification was made in the experiments but other experiments (H. E. Evans and P. P. Jennings, Trans. Faraday Soc. **61**, 2153, 1965) in this pressure range have shown that in active high frequency discharges CO_2^+ and CO^+ are the most numerous ions formed. For $p>1.5$ Torr, the electron removal rate was found to be pressure dependent, possibly as a result of electron attachment. In an extension of the work to high temperatures [5783] a value of $r=3.9\times10^{-7}$ $cm^3\ s^{-1}$, independent of pressure for $0.2<p<2$ Torr, was obtained for $T=775$ K.

3.8.i. Recombination Coefficient—Nitric Oxide

The three most recent investigations [1609, 3610, 5124] of recombination in nitric oxide, which are the only ones to include ion identification by mass spectrometer, gave results at room temperature that are in good agreement with each other. These results, together with the range of electron and gas number densities used, are given in table 8.22.

The data in [1609] and [3610] were obtained using mixtures of neon and nitric oxide in which the NO^+ ions were formed in the electronic ground state by photoionization. A long delay between successive pulses was also used to reduce complications resulting from the accumulation of negative ions. The value of r_2 given by Weller and Biondi [3610] was obtained for relatively low partial pressure (5 to 41 mTorr) of NO when the decay of the NO^+ ions, which was shown to be the only species present, followed closely the electron decay. At higher partial pressures, the dimer ion $(NO)_2^+$ became the dominant species and the measurement of electron decay under these conditions gave r_2 for $(NO)_2^+ = (1.7 \pm 0.4) \times 10^{-6}$ cm³ s⁻¹. Gunton and Shaw's [1609] value of r_2 was also obtained at relatively low partial pressures (< 1 mTorr) of NO, because at higher partial pressures a pressure dependence of the coefficient was observed. On the basis of a mass spectrometer analysis at total pressures lower than that used in the experiment, this dependence is ascribed to the presence of significant amounts of NO_2^- ions at partial pressures of NO above 1 mTorr.

Mahdavi et al. [5124] used a flowing afterglow technique in which the electron decay in a mixture of NO and Ar was measured by means of a double probe and the ions identified by means of a quadrupole mass spectrometer.

Earlier investigations using a variety of methods [840, 920, 3229] but in which there was no identification of the ions involved gave less precise values of r_2 which are not inconsistent with the values given in table 8.22.

In both [3610] and [1609] the measurements were extended to temperatures within the range $180 < T < 450$ K and gave the values of r_2 shown in figure 8.16. The value of r_2 at $T = 200$ K given in [3610] was obtained under conditions when the decay of the NO^+ ion current to the walls followed the same form as that of electron decay during the early stages of the afterglow. Under most conditions, however, it was shown that the $(NO)_2^+$ ion species was formed in considerable quantities at this temperature and this may account for the relatively high value for r_2 at $T = 186$ K obtained in [1609].

Also given in figure 8.16 is the value of r at 2900 K obtained from an investigation of the rate of decay of ionization behind a shock wave in air using microwave techniques [2491].

Analysis of the ionization occurring behind shock waves led to the conclusion [4789] that a dependence of recombination coefficient on temperature of the form $r \simeq 3 \times 10^{-3}\, T^{-3/2}$ would be consistent with the experimental observations. Data points obtained from this equation are also given in figure 8.16.

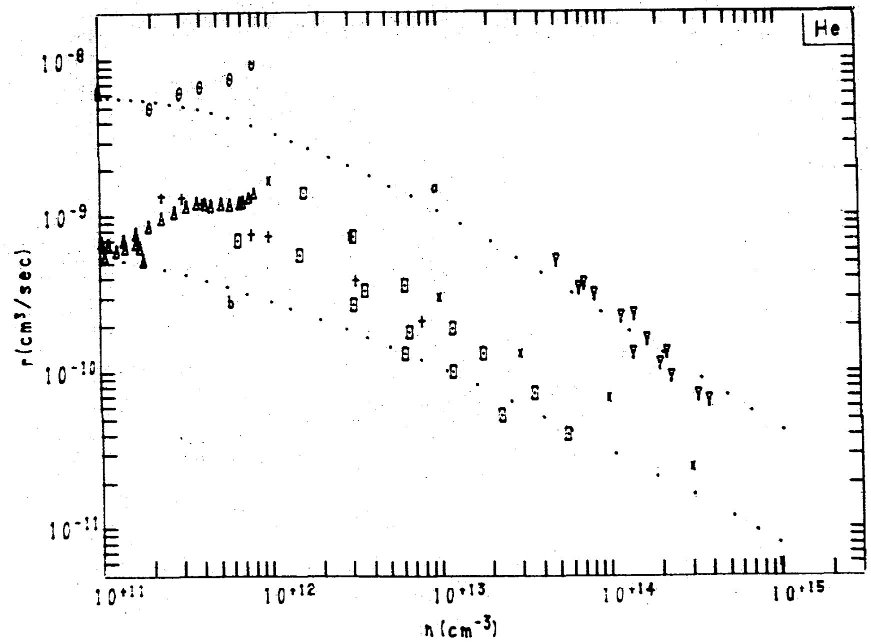
Bardsley [3462] has calculated the contribution of the $B\,^2\Pi$ and $B'\,^2\Delta$ states to the recombination coefficient for ions in their ground electronic and vibrational state and shown that this contribution varies as $T_e^{-1/2}$ as indicated in figure 8.16. The other theoretical curve shown in figure 8.16 is obtained from the expression $r_2 = 4.8 \times 10^{-8}\, (kT)^{-1/2}\, (1 - e^{-0.027/kT})$ deduced by Hansen [3476] on the assumption that excited species are present in equilibrium concentrations.

3.8.j. Recombination Coefficient—Carbon Dioxide

There is good agreement between the only published values of the recombination coefficient for CO_2 which are those obtained experimentally using static [2986] and flowing [5124] afterglow. In the experiments of Weller and Biondi [2986] the ions were produced in their ground electronic state by Penning ionization of CO_2 in a pulsed microwave discharge in a mixture of CO_2 and Ne. The nature and decay of the ions was obtained by a mass spectrometer, while the electron decay was determined by a microwave method. The apparatus was operated with long intervals between the pulses that created the ions, in order to prevent the accumulation of negative ions. Account was taken of the presence of O_2^+ ions which were observed significantly to affect the decay in the late afterglow (at times > 1 ms). At $T_g = T_e = T_i = 300$ K the value obtained for r for CO_2^+ was $(3.8 \pm 0.5) \times 10^{-7}$ cm³ s⁻¹, being constant for mixtures in which the partial pressures of CO_2 ranged from 2×10^{-4} to 2×10^{-3} Torr and that of Ne ranged from 4 to 10 Torr.

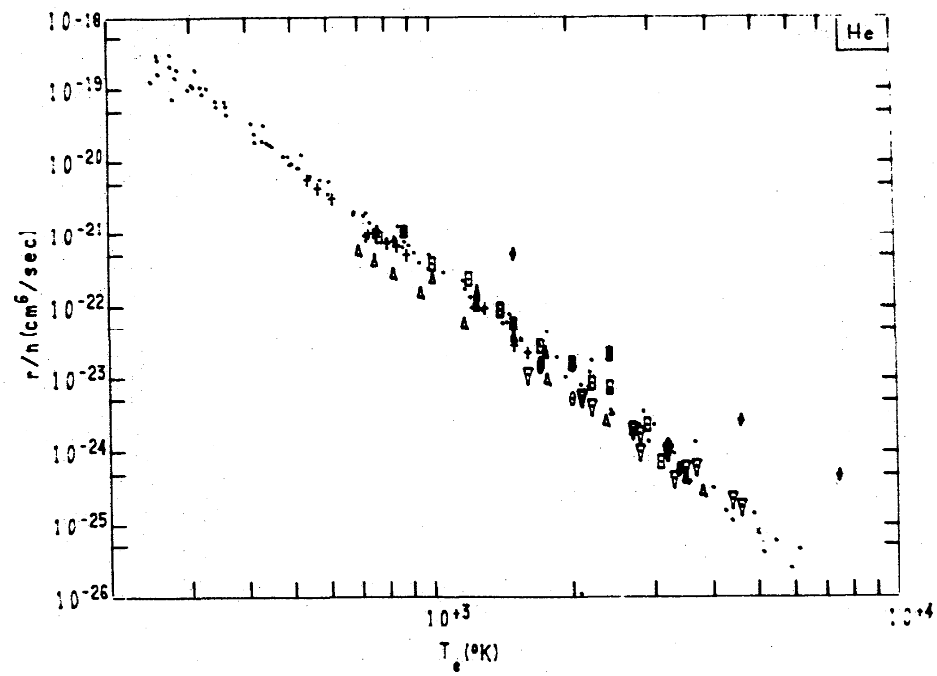
Despite some difficulty in observing the ion current decay at lower temperatures an approximate value of $r \simeq 4 \times 10^{-7}$ cm³ s⁻¹ was given for $T = 210$ K.

In the experiments of Mahdavi et al. [5124] use of a floating double probe to measure the decay of the electron concentration in a flowing afterglow in a CO_2/Ar mixture at 300 K, led to a value of $(3.4 \pm 1.2) \times 10^{-7}$ cm³ s⁻¹ under conditions when CO_2^+ ions should have been the dominant species.



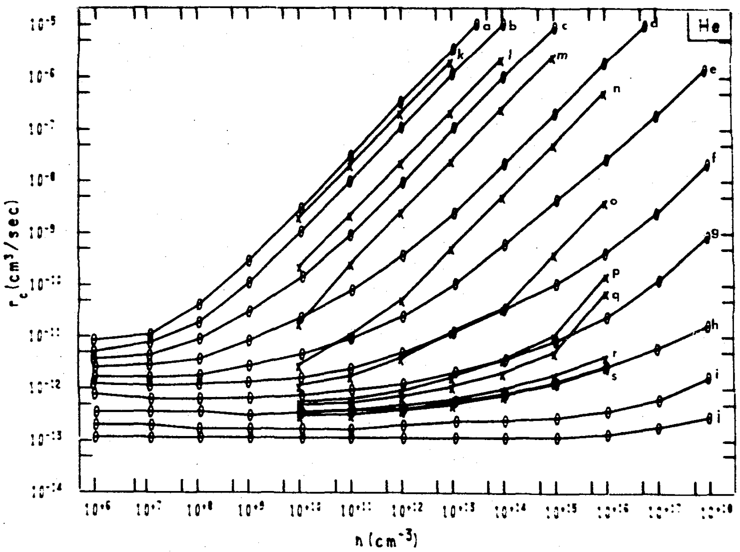
Experimental: Δ Mosburg(883); ⊟ Hinnov(1639) also includes Motley(2331) as given in (1639); + Anisimov(1870); ∇ Gusinow(1961); θ Aleskovskii(2447); x Newton(3658).
Theoretical: · a ,· b Bates(2168). (See text for details).

FIGURE 8.1. Recombination coefficient for helium as a function of electron density n for $n > 10^{11}$ cm^{3}.



Experimental: θ Robben(759); ⊟ Hinnov(1639) including Motley and Kuckes; + Anisimov(1870); ∇ Gusinow(1961); Δ Born(3464); x Newton(3658); ♦ Chen(5745).
Theoretical: · Bates(2168); ▲ Mansbach(5761).

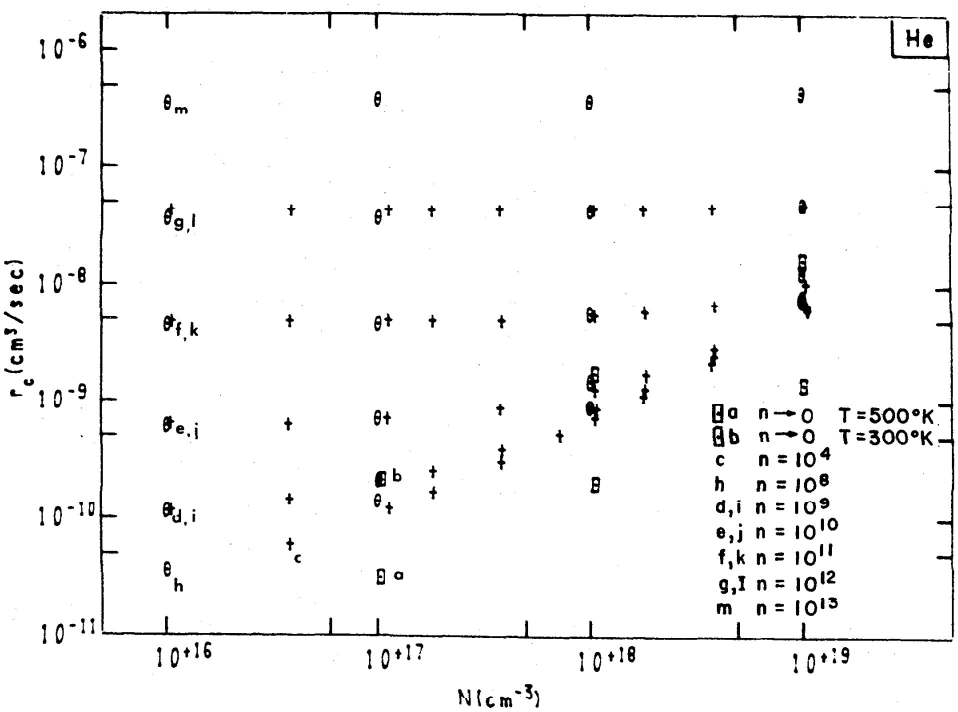
FIGURE 8.2. Comparison of experimental and theoretical values for r/n, T_e for helium.



Theoretical: θ Drawin(5732); x Chen(5745).

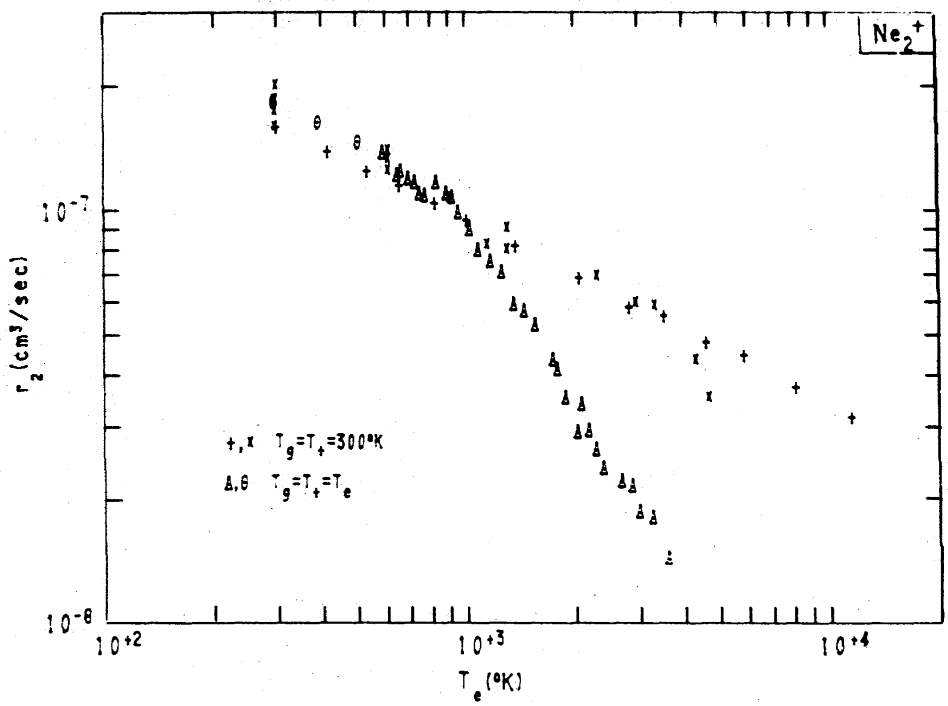
θ a T_e=125 K	θ f T_e=4000 K	x k T_e=300 K	x p T_e=8000 K
θ b T_e=250 K	θ g T_e=8000 K	x l T_e=500 K	x q T_e=10000 K
θ c T_e=500 K	θ h T_e=16000 K	x m T_e=1000 K	x r T_e=14000 K
θ d T_e=1000 K	θ i T_e=32000 K	x n T_e=2000 K	x s T_e=16000 K
θ e T_e=2000 K	θ j T_e=64000 K	x o T_e=4000 K	

FIGURE 8.3. Recombination coefficient as a function of electron density for helium at various values of T_e in an optically thin plasma.



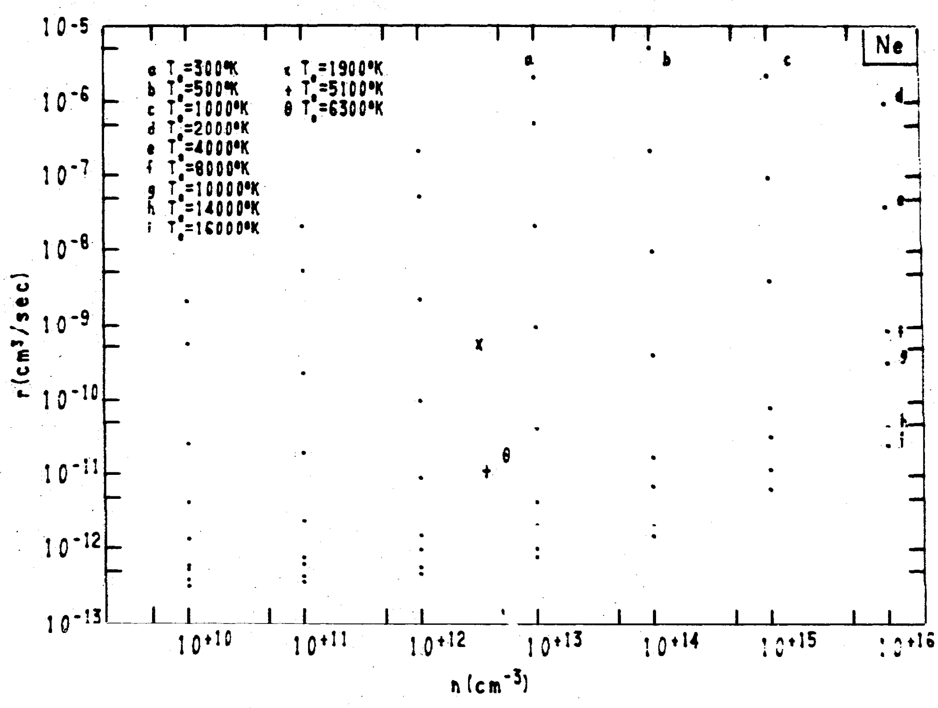
Theoretical: ⊟ Bates(1259); θ Collins(5773); + Deloche(5774).

FIGURE 8.4. Theoretical values for the collisional radiative recombination coefficient for helium as a function of gas number density for various values of the electron concentration.



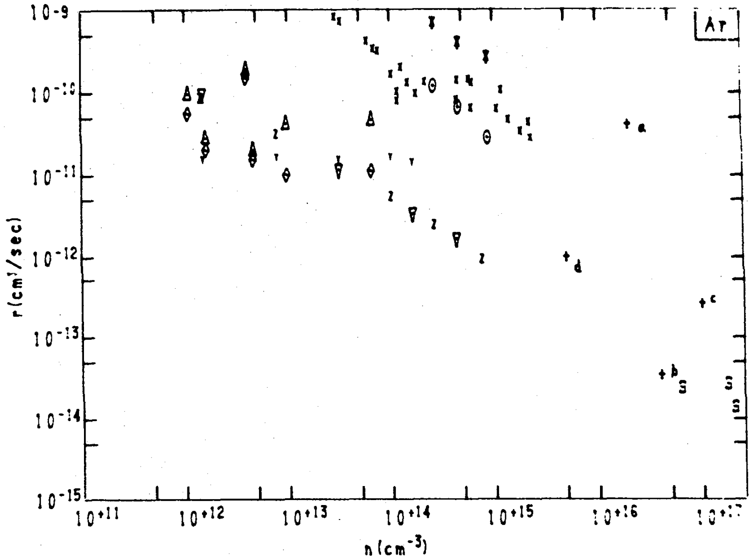
Experimental: θ Kasner(2988); + Frommhold(3443); Δ Cunningham(4585); x Philbrick(4044).

FIGURE 8.5. Temperature dependence of the dissociative recombination coefficient for neon.



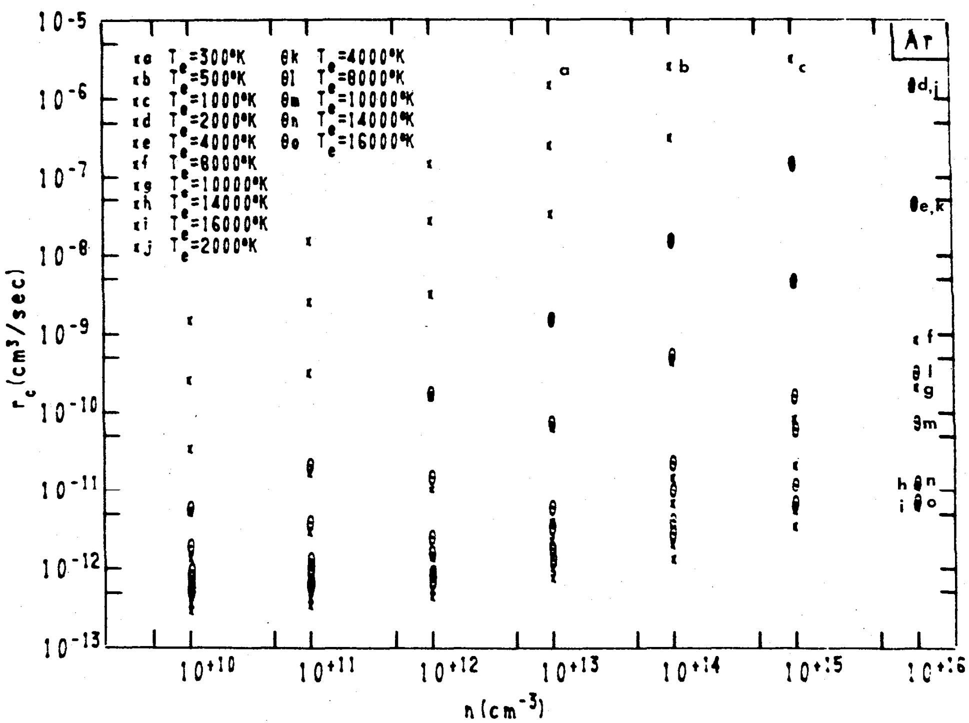
Experimental: θ, +, x Chen(5745).
Theoretical: • Chen(5745).

FIGURE 8.6. Comparison of experimental values of r for plasmas of high electron concentration in neon, with approximate theoretical values calculated on the basis of collisional recombination theory.



Experimental: ϴ Gusinow(1961); +a Aleksandrov(3433); x Funahashi(3468); +b Hughes(5240); Δ Chen(5745); +c Olsen(5775); ⊟ Mitin(5776); +d Van Trong(5777); ∇ Desai(5782).
Theoretical: ⌶ Gusinow(1961); ϴ Chen(5745); Y Desai(5782) (Collisional radiative recombination coefficient); Z Desai(5782) (dissociative molecular-ion recombination coefficient).

FIGURE 8.7. Recombination coefficient as a function of electron concentration for quasi-equilibrium plasmas in argon. The theoretical values were calculated using different methods, but all on the basis of collisional radiative recombination except those of Desai (labeled Z) which were calculated on the basis of dissociative recombination.



Theoretical: ϴ Wanless(5201); x Chen(5745).

FIGURE 8.8. Theoretical values of the collisional radiative recombination coefficient for argon as a function of n at various values of T_e.

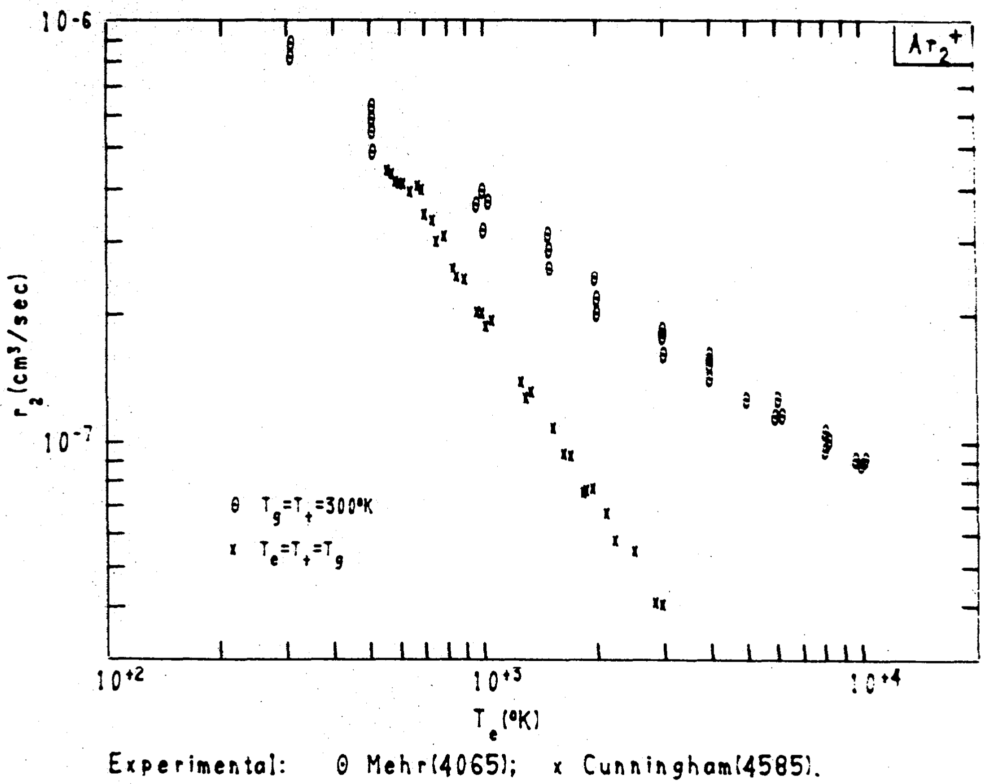


FIGURE 8.9. Temperature dependence of the dissociative recombination coefficient for argon.

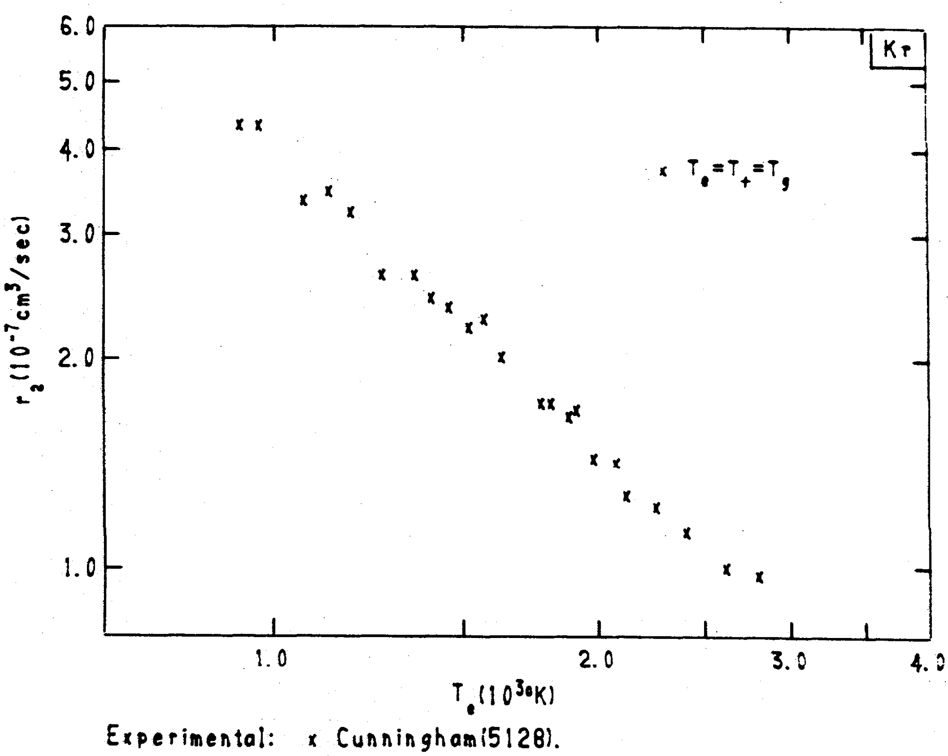
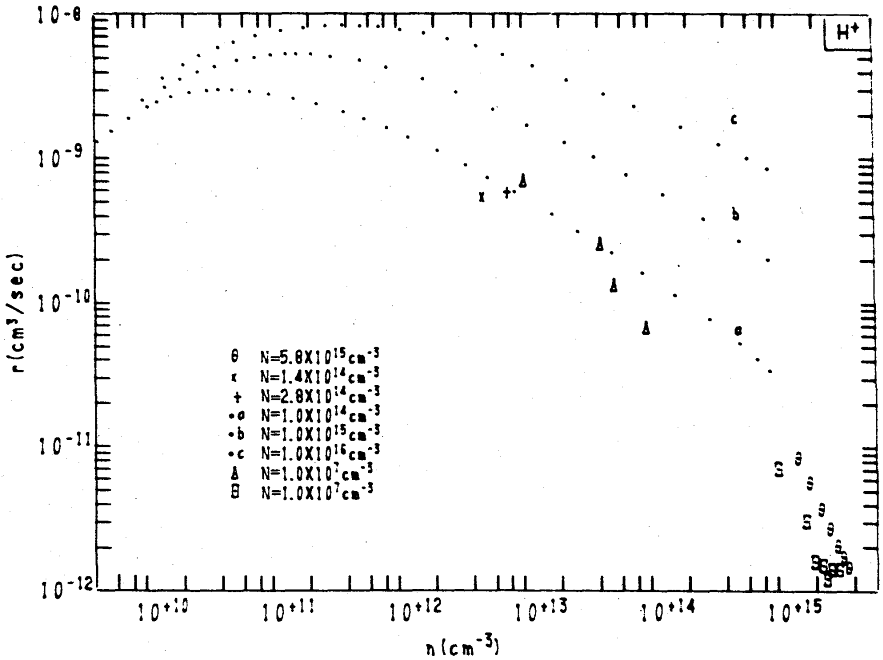
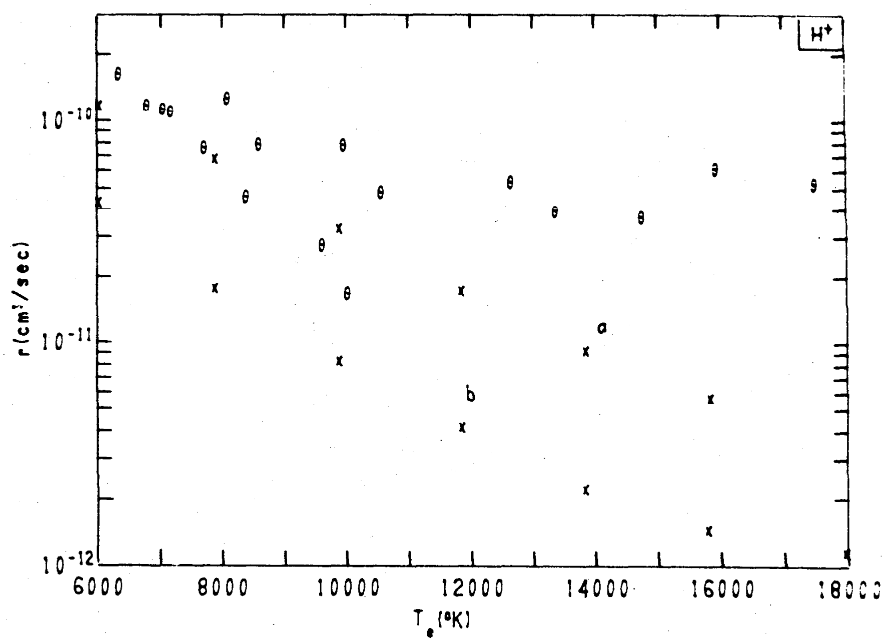


FIGURE 8.10. Temperature dependence of the dissociative recombination coefficient for krypton.



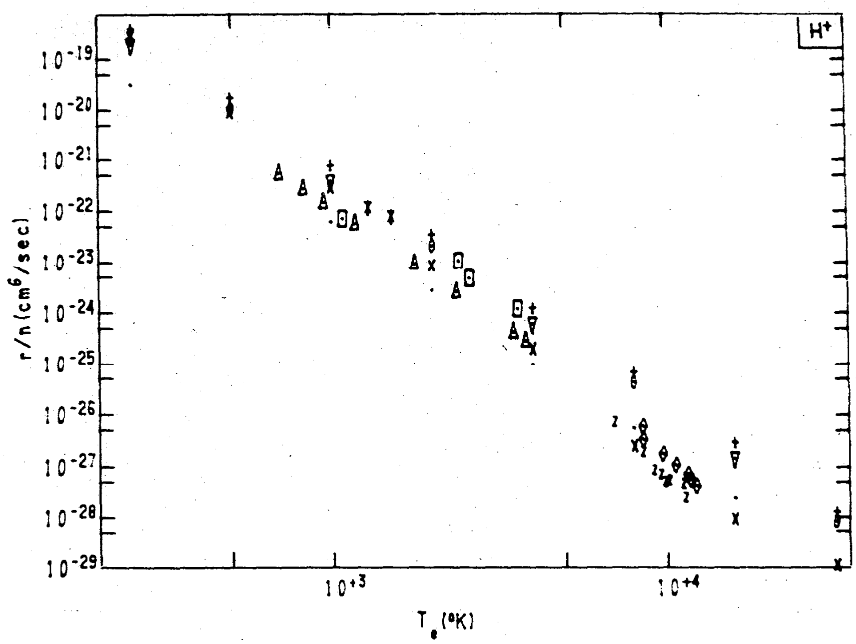
Experimental: Θ Cooper(1389); x,+ Hinnov(1639). Δ Brand(5778); ⊟ Irons(5779).
Theoretical: •a,•b,•c Bates(2147).

FIGURE 8.11. Comparison of experimental recombination coefficients with computed values of r_c for optically thick, magnetically confined plasmas in hydrogen.



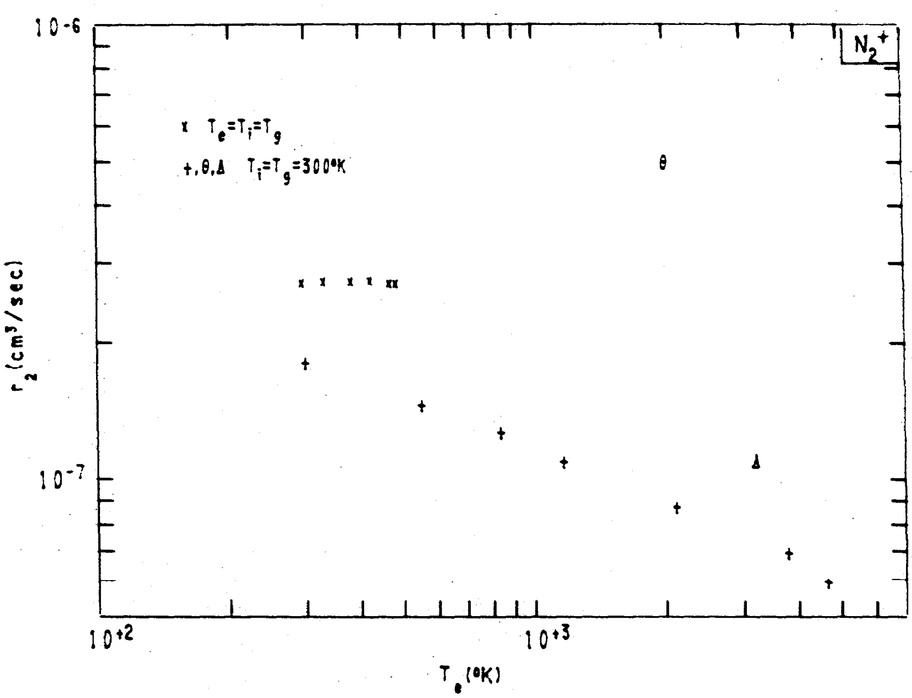
Experimental: Θ Janssen(5697).
Theoretical: xa Janssen(5697) using results of Bates(444) for an optically thin plasma. xb Janssen(5697) using results of Bates(146) for an optically thick plasma.

FIGURE 8.12. Comparison of experimental recombination coefficients for decaying spark channels with computed values of r_c for atomic hydrogen in optically thin plasmas.



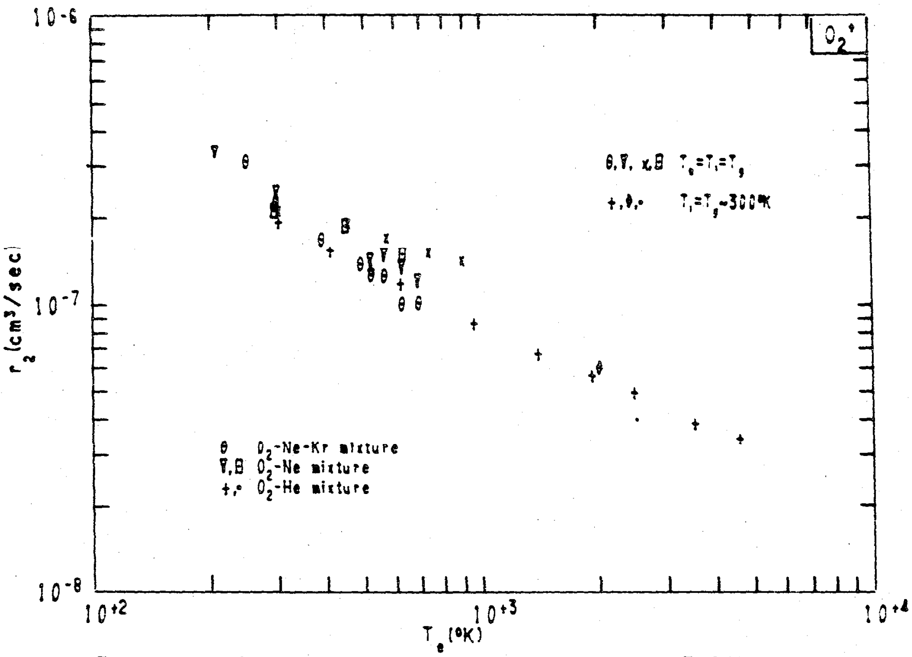
Experimental: ◊ Cooper(1389); ⧗ Hinnov(1639); ⊡ Brand(5778); Z Irons(5779).
Theoretical: x Bates(444); + Makin(640); θ D'Angelo(1614); ∇ Hinnov(1639); Δ Mansbach(5761); · Curry(5781).

FIGURE 8.13. Comparison of the theoretical values of the *collisional* recombination coefficient r_3 for hydrogen using various theoretical models with experimental values of the recombination coefficient.



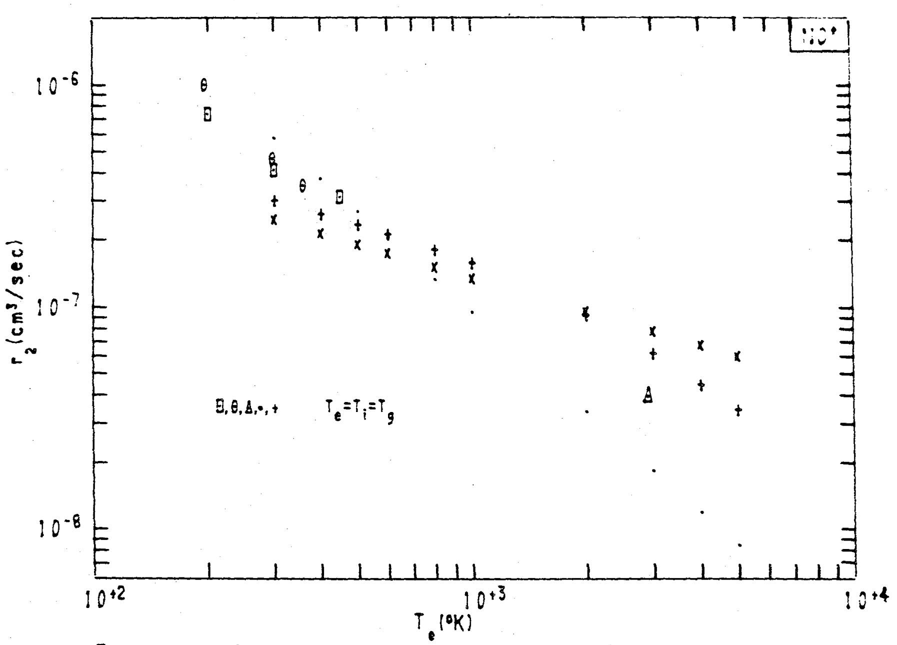
Experimental: x Kasner(2993); + Mehr(4045); θ Sayers(4605); Δ Sayers(4681).

FIGURE 8.14. Temperature dependence of the dissociative recombination coefficient of N_2^+ ions.



Experimental: θ,∇ Kasner(3611); x Mentzoni(3428); B Smith(3786); + Mehr(4045); θ Sayers(4605); • Sayers(4681).

FIGURE 8.15. Experimental values of the dissociative recombination coefficient for O_2^+ as a function of temperature.



Experimental: θ Gunton(1609); Δ Stein(2491); B Weller(3610).
Theoretical: • Lin(4789); x Bardsley(3462)(partial coefficient-see text); + Hansen(3476).

FIGURE 8.16. Temperature dependence of the recombination coefficient for NO^+ ions and electrons. (In [3462] r_2 is a partial recombination coefficient representing the contribution of only the $B\,^2\Pi$ and $B'\,^2\Delta$ states.)

Table 8.1

Theoretically computed values for the collisional radiative recombination coefficient for the reaction $He^+ + e + e \rightarrow He + e$ for magnetically confined plasmas (A) optically thin and (B) optically thick to resonance lines

$N(cm^{-3})$	$n(10^{11}cm^{-3})$	T_e(°K) Case A	T_e(°K) Case B	T_i(°K) Case A	T_i(°K) Case B	$r_c(10^{-10}cm^3/sec)$ Case A	$r_c(10^{-10}cm^3/sec)$ Case B
10^{12}	.01		311		289		1.82
	.05	283	435	284	403	9.4	1.57
	.10	318	526	319	492	10.6	1.25
	.50	449	846	440	818	8.4	.64
	1.0	549	987	535	963	6.3	.51
	5.0	919	1770	915	1750	2.63	.213
	10.	1180	2200	1185	2200	1.70	.170
	50.	2180	3680	2190	3670	.59	.066
	100.	2850		2930		.35	
10^{13}	.05	256	357	252	293	14.8	3.3
	.10	274	408	266	329	20.3	3.3
	.50	362	604	339	482	21.8	2.66
	1.0	432	722	399	591	18.8	1.95
	5.0	682	1170	653	1020	10.1	1.10
	10.0	895	1470	877	1320	6.6	.77
	50.0	1450	2410	1430	2234	2.97	.34
	100.	1850	3000	1820	2810	1.92	.226
	500.	3230	4580	3190	4500	0.64	.089
	1000.		5450		5323		.058
10^{14}	.01		273		245		3.0
	.05		327		256		5.0
	.10	257	361	231	262	25.6	5.6
	.50	306	491	272	315	53.	5.9
	1.0	344	577	299	363	58	5.5
	5.0	496	873	429	577	45	3.7
	10.	600	1060	531	737	35	2.86
	50.	984	1690	924	1300	15.8	1.46
	100.	1240	2070	1180	1660	10.5	1.06
	500.	2170	3310	2100	3870	3.7	.47
	1000.	2780	4000	2700	3580	2.27	.32
	5000.	4900	5880	4800	5630	.70	.123
	10000.	6140		6130		.44	
10^{15}	.05		303		230		5.8
	.10		342		238		6.7
	.50	281	455	236	260	72.	8.0
	1.0	321	519	252	272	85.	8.0
	5.0	442	735	311	331	90.	7.1
	10.	517	865	342	385	81.	6.3
	50.	774	1290	524	643	52.	4.3
	100	940	1550	670	843	39.	3.4
	500	1550	2410	1240	1560	16.0	1.81
	1000	1940	2910	1610	2040	10.4	1.32
	5000	3390	4390	2950	3640	3.3	.57
	10000		5130		4440		.39
10^{16}	.01		166		224		3.7
	.05		247		232		6.5
	.10		276		235		7.4
	.50	258	415	229	244	80.	9.1
	1.0	298	501	236	248	97	9.4
	5.0	416	712	253	257	117	8.9
	10.0	481	833	261	264	115	8.3
	50.0	680	1210	311	323	92	6.6
	100.	800	1420	357	375	78	5.8
	500	1220	2090	586	630	47	3.9
	1000	1490	2450	782	835	35	3.2
	5000	2420	3580	1550	1690	15.5	1.95
	10000		4250		2220		1.53

Theoretical:

All data taken from Bates, et al., Proc. Roy. Soc. (London), 279A, 32 (1964).

Table 8.2
Experimental values of the recombination coefficient for helium for $n > 10^{11}\text{cm}^{-3}$

$n(10^{11}\text{cm}^{-3})$	$r(10^{-10}\text{cm}^3/\text{sec})$	$T_e(10^3\,°\text{K})$	$T_g(°\text{K})$	$N(\text{cm}^{-3})$	
42	0.58	1.7			(a)
160	0.19	3.2			(a)
190	3.0	1.7			(a)
260	8.9	1.5			(a)
660	3.4	2.0			(a)
4400	2.5	3.4			(a)
1.00	6.8		300	In range from 2.5 to 42×10^{16}	(b)
1.06	6.7				
1.06	5.6				
1.11	6.6				
1.14	5.6				
1.22	6.8				
1.26	6.0				
1.37	7.1				
1.42	6.4				
1.61	6.7				
1.63	7.8				
1.72	6.4				
1.78		0.610			
1.79	5.3				
1.81	5.2				
1.92	8.6				
2.31	9.6				
2.73	11				
3.2	11				
3.7	12				
3.8		0.750			
4.0	12				
4.2	12				
4.5	12				
5.2	12				
5.9	12				
6.6	12				
7.0	12				
7.5	13				
7.9		0.730			
8.1	14				
36	3.3	1.4			(c)
62	3.6	1.5			(c)
66	1.8	1.7			(c)
120	1.0	2.2			(c)
180	1.3	2.2			(c)
230	0.53	2.9		0.42×10^{14}	(c)
360	0.73	2.7		3.5×10^{14}	(c)
560	0.40	3.1		1.35×10^{14}	(c)
6.5	7.0	0.87			(d)
15	5.6	1.0			(d)
16	14	0.77			(d)
31	{2.7, 7.3}	{1.4, 1.2}			(d)
61	3.7	1.5			(d)
62	1.3	2.4		0.18×10^{14}	(d)
120	1.9	2.0			(d)
180	1.3	2.4		1.4×10^{14}	(d)

Table 8.2 (continued)

Experimental values of the recombination coefficient for helium for $n > 10^{11} cm^{-3}$

$n(10^{11} cm^{-3})$	$r(10^{-10} cm^3/sec)$	$T_e(10^3 °K)$	$T_g(°K)$	$N(cm^{-3})$	
2.2		0.53	300	In range from 7×10^{14} to 7×10^{15}	(e)
2.3	13				
2.90		0.56			
3.1	13				
3.9		0.59			
4.0	12				
5.9		0.69			
7.7		0.76			
7.9	7.5				
9.4		0.81			
9.8	7.3				
28.1		1.2			
32	3.8				
53		1.4			
78	2.1				
2.2		0.73	500	In range from 7×10^{14} to 7×10^{15}	(e)
2.4	2.1				
2.9		0.72			
3.2	3.1				
3.9		0.75			
4.0	3.9				
5.7		0.79			
6.1	4.3				
7.6		0.83			
7.9	5.1				
9.5		0.87			
10	4.9				
27		1.20			
32	2.9				
51		1.45			
79	1.7				
490	5.1	1.6		2.5×10^{17}	(f)
660	3.4	2.1			
710	3.6	2.1			
820	3.1	2.2			
1200	2.2	2.7			
1400	{1.3, 1.3, 2.3}	{2.8, 3.2, 2.8}			
1700	1.6	3.2			
2000	1.1	3.5			
2200	1.3	3.7			
2300	0.92	3.3			
3300	0.70	4.4			
3900	0.65	4.6			
1.0	63			$<3.54\times10^{15}$	(g)
2.0	50				
3.0	62				
4.0	68				
6.0	76				
8.0	96				

Table 8.2 (continued)

Experimental values of the recombination coefficient for helium for $n > 10^{11} cm^{-3}$

$n(10^{11} cm^{-3})$	$r(10^{-10} cm^3/sec)$	$T_e(10^3 {}^\circ K)$	$T_g({}^\circ K)$	$N(cm^{-3})$	
25	11		750	In range from 8.8×10^{15} to 7.1×10^{17}	(h) $T_e=T_i=T_g$ for the lower electron densities and higher temperatures, but $T_e > T_g$ for higher electron densities and lower temperatures
	6.3		1000		
	4.0		1250		
50	9.6		750		
	5.8		1000		
	5.2		1250		
	2.9		1500		
100	6.4		750		
	5.6		1000		
	4.9		1250		
	3.8		1500		
	2.3		1750		
200	3.1		1750		
	1.4		2000		
10	17	0.73			(i)
30	7.3	1.2			
100	3.0	1.6			
300	1.3	2.4			
400		4.0†			
1000	0.68	3.5			
3000	0.25	5.0†			
10000	0.06	10			

†Measured values of T_e; all other values of T_e given in this section of the table are calculated.

Theoretical:

(a) Robben, et al., Phys. Rev. 132, 2363 (1963). Data obtained using a plasma jet.
(b) Mosburg, Phys. Rev. 152, 166 (1966).
(c) Hinnov, et al., Phys. Rev. 125, 795 (1962).
(d) Motley and Kuches as given in (c).
(e) Anisimov, et al., Sov. Phys. Tech. Phys. (Eng. transl.) 10, 1554 (1964).
(f) Gusinow, et al., Phys. Rev. 149, 91 (1966).
(g) Aleskovskii, et al., Soviet Phys. JETP (Eng. transl.) 16, 887 (1963).
(h) Born, Phys. Rev. 169, 155 (1968).
(i) Newton, et al., J. Phys. (B) 1, 669 (1968).

Table 8.3(a)

Theoretically computed values of the collisional-radiative recombination coefficient for optically thin helium plasma

n_e (10^{12}cm^{-3}) \ T(°K)	125	250	500	1000	2000	4000	8000	16000	32000	64000
	r_c (10^{-10}cm^3-sec^{-1})									
0.000001	0.083	.049	.035	.025	.016	.012	.0078	.0035	.0019	.0011
0.00001	0.11	.074	.043	.028	.016	.011	.0063	.0035	.0019	.0011
0.0001	0.40	.18	.089	.037	.018	.012	.0063	.0035	.0017	.0011
0.001	2.9	1.1	.30	.085	.027	.013	.0065	.0031	.0017	.0011
0.01	30.	10.	1.4	.23	.047	.016	.0074	.0035	.0017	.0011
0.1	300.	100.	9.1	.79	.093	.023	.0095	.0038	.0017	.0011
1.0	3300.	1100.	95.	3.7	.25	.049	.012	.0041	.0019	.0011
10.0	35000.	12000.	1100.	25.	1.1	.12	.021	.0058	.0023	.0011
100.0		100000.	10000.	220.	6.2	.35	.036	.0079	.0024	.0011
1000.0			91000.	2000.	45.	1.1	.081	.013	.0028	.0012
10000.0				19000.	270.	4.1	.24	.026	.0038	.0013
100000.0					1900.	25.	1.3	.060	.0063	.0018
1000000.0					14000.	220.	8.9	.17	.017	.0030

Table 8.3(b)

Theoretically computed values of the collisional-radiative recombination coefficient for helium plasma optically opaque to the resonance lines

n_e (10^{12}cm^{-3}) \ T(°K)	250	500	1000	2000	4000	8000	16000	32000	64000
	r_c (10^{-10}cm^3-sec^{-1})								
.000001	.050	.027	.022	.013	.0093	.0060	.0028	.0013	.00087
.00001	.068	.035	.025	.017	.0098	.0069	.0028	.0016	.00078
.0001	.17	.060	.035	.021	.010	.0066	.0031	.0015	.00087
.001	1.1	.23	.065	.030	.013	.0076	.0030	.0015	.00087
.01	11.	1.4	.19	.055	.017	.0085	.0026	.0016	.00081
.1	120.	11.	.71	.11	.025	.010	.0026	.0015	.00087
1.0	1300.	120.	3.5	.28	.047	.013	.0025	.0014	.00083
10.0	12000.	1100.	25.	.98	.10	.017	.0024	.0013	.00093
100.0	87000.	9800.	210.	5.0	.27	.021	.0020	.0012	.00093
1000.		91000.	2100.	33.	.78	.027	.0017	.0013	.00093
10000.			22000.	260.	3.4	.10	.0028	.0013	.00093
100000.				1800.	20.	.81	.011	.0018	.0011
1000000.				11000.	240.	9.5	.083	.0076	.0019

Theoretical:

All data taken from Drawin, et al., Z. Physik 243, 326 (1971).

Table 8.4(a)

Theoretically computed values of the collisional-radiative recombination coefficient for helium: $T_e = T_g = T$

$n(10^{12}cm^{-3})$	$N(10^{16}cm^{-3})$ \ T(°K)	125	250	300	500	1000	2000	4000	8000	32000	
		$r_c(10^{-11}cm^3\text{-}sec^{-1})$									
	10	147	20.8		3.1	0.70	0.22	0.088			(a)
	100	1470	175.		20	2.70	0.50	0.14			(a)
n→0	1000	14200	1650.		144	10.6	1.38	0.238			(a)
	10000	141000	16800.		980	42	2.14	0.44			(a)
	100000		159000.		3900	113	4.3	0.58			(a)
.0001	1.			3.61							(b)
	10.			14.0							(b)
	100.			90.							(b)
	1000.			770							(b)
.001	1.			11.5							(b)
	10.			21.4							(b)
	100.			90.							(b)
	1000.			760							(b)
.01	1.			61							(b)
	10.			71							(b)
	100.			149							(b)
	1000.			820							(b)
.1	1.			450							(b)
	10.			450							(b)
	100.			560							(b)
	1000.			1290							(b)
1.0	1.			3600							(b)
	10.			3700							(b)
	100.			4300							(b)
	1000.			4900							(b)
10.	1.			35000							(b)
	10.			38000							(b)
	100.			37000							(b)
	1000.			45000							(b)
.001	.000001					.56	.33	.15	.065	.015	(c)
	.00001					.63	.33	.17	.059	.015	(c)
	.0001					.87	.42	.17	.060	.014	(c)
	.001					1.6	.53	.20	.059	.014	(c)
	.01					3.2	.89	.22	.059	.011	(c)
	.1					7.6	2.0	.30	.059	.0093	(c)
	1.0					31.	7.8	.54	.060	.0085	(c)
	10.					220.	27.0	1.3	.060	.0093	(c)
	100.					2400.	130.0	4.0	.059	.011	(c)
	1000.					29000.	710.0	16.0	.058	.015	(c)
.1	.000001					6.9	.91				(c)
	.00001					6.9	.79				(c)
	.0001					6.9	.87				(c)
	.001					6.6	.96	.25			(c)
	.01					12.	1.1	.31			(c)
	.1					25.	2.1	.45			(c)
	1.0					71.	7.4	.91			(c)
	10.					300.	28.	2.0			(c)
	100.					2500.	120.	5.0			(c)
	1000.					29000.	710.	16.			(c)

Table 8.4(a) continued

Theoretically computed values of the collisional-radiative recombination coefficient for helium: $T_e = T_g = T$

$n(10^{12}cm^{-3})$	$N(10^{16}cm^{-3})$ \ T(°K)	125	250	300	500	1000	2000	4000	8000	32000	
				$r_c(10^{-11}cm^3\text{-}sec^{-1})$							
1.0	.000001					35	2.3	--			(c)
	.00001					34	2.3	--			
	.0001					33	2.4	.28			
	.001					33	2.5	.33			
	.01					37	2.6	.49			
	.1					62	3.6	.78			
	1.					150	8.7	1.6			
	10.					420	30.	3.2			
	100.					2450	135.	6.5			
	1000.					29000	710.	16.0			
10.0	.000001					250	11.0	--	--	.012	
	.00001					250	10.0	--	--	.012	
	.0001					250	10.0	--	.15	.012	
	.001					250	10.0	--	.15	.011	
	.01					250	11.0	.87	.15	.0093	
	.1					260	12.0	1.0	.15	.0083	
	1.0					360	19.0	1.7	.13	.0083	
	10.					760	45.0	3.2	.10	.0093	
	100.					2500	150.	6.5	.074	.011	
	1000.					29000	710.	16.0	.065	.015	
.001	0.1					5.6	0.66	0.18			(d)
	1.0					23.	1.9	.27			
	10.0					150.	7.7	.43			
	100.0					1800.	49.	.88			
	1000.0					20000.	340	2.6			
0.1	0.1					19.	1.3	0.27			
	1.0					60.	2.9	0.38			
	10.0					190.	9.1	0.54			
	100.0					1800.	52.	0.96			
	1000.0					20000.	340	2.6			
1.0	0.1					43.	3.2	0.43			
	1.0					120.	4.3	0.52			
	10.0					330	10.0	0.68			
	100.0					1900	54.	1.0			
	1000.0					20000	340.	2.6			
10.0	0.1					190	4.3	.95			
	1.0					280	5.4	1.1			
	10.0					510	12.	1.2			
	100.0					2000	55.	1.3			
	1000.0					20000	340	2.6			
.00000001	4.0			5.8							(e)
	10.0			11.8							
	20.0			16.6							
	40.0			29.9							
	80.0			51.							
	100.0			71.							
	200.0			110							
	400.0			214							
	1000.0			610							

Table 8.4(a) continued

Theoretically computed values of the collisional-radiative recombination coefficient for helium: $T_e = T_g = T$

$n(10^{12}cm^{-3})$	$N(10^{16}cm^{-3})$ \ T(°K) $r_c(10^{-11}cm^3\text{-}sec^{-1})$: 125	250	300	500	1000	2000	4000	8000	32000	
.001	1.0		11.4							
	4.0		14.2							
	20.0		25.1							
	40.0		38.							
	100.0		85.							
	200.0		130							
	400.0		243							
	1000.		660							
.01	1.0		63.							
	4.0		63.							
	10.0		69.							
	40.0		85.							
	100.		127.							
	200.		172							
	400.		284							
	1000.		660							
0.1	1.0		470							(e)
	4.0		470							
	10.0		480							
	20.0		480							
	40.		480							
	100.		540							
	200.		580							
	400.		680							
	1000.		1030							
1.0	1.0		4200							
	4.0		4200							
	12.6		4200							
	20.0		4100							
	40.0		4200							
	100.		4300							
	200.		4400							
	400.		4500							
	1000.		4800							

Theoretical:

(a) Bates, et al., Proc. Phys. Soc. (London) 85, 231 (1965).
(b) Collins, Phys. Rev. 177, 254 (1968).
(c) Drawin, et al., Z. Physik 254, 202 (1972). (For plasma optically opaque to resonance lines).
(d) Drawin, et al., Z. Physik 254, 202 (1972). (For plasma optically opaque to resonance lines and resonance continuum).
(e) Deloche, et al., J. Phys. (Paris) 29, C3-27-30 (1968).

Table 8.4(b)

Theoretically computed values of the collisional-radiative recombination coefficient for helium: T_g = 300°K, T_e = 500°K

n ($10^{12}cm^{-3}$)	N ($10^{16}cm^{-3}$)	r_c ($10^{-11}cm^3sec^{-1}$)	n ($10^{12}cm^{-3}$)	N ($10^{16}cm^{-3}$)	r_c ($10^{-11}cm^3sec^{-1}$)
.0001	1.	1.59	0.1	1	54.
	10.	5.7		10	53.
	100.	43.		100	73.
	1000.	390		1000	299.
.001	1.	2.99	1.0	1	390
	10.	6.1		10	450
	100.	38.		100	420
	1000.	390.		1000	600
.01	1.	9.7	10.0	1	3600
	10.	11.9		10	3600
	100.	37.		100	3600
	1000.	350.0		1000	4100

Theoretical:
All data taken from Collins, Phys. Rev. 177, 254 (1968).

Table 8.4(c)

Theoretically computed values of the collisional-radiative recombination coefficient for helium: T_g = 300°K, T_e = 1000°K

n ($10^{12}cm^{-3}$)	N ($10^{16}cm^{-3}$)	r_c ($10^{-11}cm^3sec^{-1}$)	n ($10^{12}cm^{-3}$)	N ($10^{16}cm^{-3}$)	r_c ($10^{-11}cm^3sec^{-1}$)
.0001	1.	0.55			
	10.	2.15	0.1	10	4.3
	100.	14.1		100	5.5
	1000.	132.		1000	49.
.001	10	1.67	1.0	10	20.8
	100	12.8		100	19.6
	1000	122.		1000	31.
.0001	10	1.69	10.0	1	113
	100	6.9		10	880
	1000	112.		100	111
				1000	132

Theoretical:
All data taken from Collins, Phys. Rev. 177, 254 (1968).

Table 8.4(d)

Theoretically computed values of the collisional-radiative recombination coefficient for helium: T_g = 300°K, T_e = 2000°K

n ($10^{12}cm^{-3}$)	N ($10^{16}cm^{-3}$)	r_c ($10^{-11}cm^3sec^{-1}$)	n ($10^{12}cm^{-3}$)	N ($10^{16}cm^{-3}$)	r_c ($10^{-11}cm^3sec^{-1}$)
.0001	1	.222	.1	1	.71
	10	.74		10	.74
	100	5.0		100	.89
	1000	46.		1000	8.0
.001	1	.262	1.0	1	1.78
	10	.55		10	1.86
	100	4.2		100	1.81
	1000	42.		1000	2.96
.01	1	.400	10	1	7.1
	10	.52		10	7.3
	100	1.81		100	7.0
	1000	34.		1000	7.4

Theoretical:
All data taken from Collins, Phys. Rev. 177, 254 (1968).

Table 8.5

Experimental values of the dissociative recombination coefficient of electrons and Ne_2^+ ions for $T_e = T_+ = T_g$ = 300°K

	r_2 ($10^{-7}cm^3/sec$)	$r_{2\ corr}^*$ ($10^{-7}cm^3/sec$)	n ($10^{10}cm^{-3}$)	N ($10^{17}cm^{-3}$)
(a)	2.0	1.7	0.11 to 1.2	6.4
(b)	2.2	1.8	0.028 to 2.0	5.5 to 11
(c)	3.4	1.9	0.05 to 0.22	8.3
(d)	2.1	1.7	0.066 to 0.59	4.8 to 9.7
(e)	2.0	2.0	1 to 10	23
(f)	2.4	1.8	0.18 to 1.2	5.8 to 6.4
(g)	1.8	1.8	0.023 to 0.44	2.6 to 9.7
(h)		1.7	0.012 to 0.29	6.4
(i)	1.75	1.75	0.058 to 0.96	1.9

*$r_{2\ corr}$ are the values by Frommhold, Biondi and Mehr (3443) when the original values (r_2) were corrected by them for diffusion and for the initial distribution of ions and electrons in the plasma.

Experimental:
(a) Hess, Z. Naturforsch 20A, 451 (1965).
(b) Oskam, et al., Phys. Rev. 132, 1445 (1963).
(c) Biondi, Phys. Rev. 129, 1181 (1963).
(d) Biondi, et al., Phys. Rev. 76, 1697 (1949).
(e) Connor, et al., Phys. Rev. 140, A778 (1965).
(f) Oskam, Philips Res. Rept. 13, 401 (1958).
(g) Kasner, Scientific Paper 67-1E2-GASES-P3, Westinghouse Research Laboratories (1967).
(h) Frommhold, et al., Phys. Rev. 165, 44 (1968).
(i) Philbrick, et al., Phys. Rev. 181, 271 (1969).

Table 8.6(a)

Experimental values for the temperature variation of the dissociative recombination coefficient of electrons and Ne_2^+ ions: $T_e = T_g = T_+$

T_e (°K)	r (10^{-8} cm^3/sec)		T_e (°K)	r (10^{-8} cm^3 sec)		T_e (°K)	r (10^{-8} cm^3 sec)	
290	18	(a)	880	11	(b)	1900	3.5	(b)
390	16	(a)	910	11	(b)	2000	2.9	(b)
500	15	(a)	950	9.9	(b)	2100	3.4	(b)
580	14	(b)	1000	9.0	(b)	2200	3.0	(b)
640	12	(b)	1100	8.0	(b)	2300	2.7	(b)
			1200	7.5	(b)	2400	2.4	(b)
660	12	(b)						
690	12	(b)	1300	7.1	(b)	2700	2.2	(b)
720	12	(b)		5.9	(b)	2800	2.2	(b)
740	11	(b)	1400	5.7	(b)	3000	1.9	(b)
770	11	(b)	1500	5.3	(b)	3200	1.8	(b)
830	12	(b)	1700	4.4	(b)	3600	1.4	(b)
			1800	4.1	(b)	4600	3.5	(b)

Experimental:

(a) Kasner, Scientific Paper 67-1E2-GASES-P3, Westinghouse Research Laboratories (1967).

(b) Cunningham, et al., Phys. Rev. 185, 98 (1969).

Table 8.6(b)

Experimental values for the temperature variation of the dissociative recombination coefficient of electrons and Ne_2^+ ions: $T_g = T_+ = 300°K$

T_e (°K)	r (10^{-8} cm^3/sec)		T_e (°K)	r (10^{-8} cm^3/sec)		T_e (°K)	r (10^{-8} cm^3/sec)	
300	20	(a)	650	11	(b)	2800	5.8	(b)
	19	(a)	820	10	(b)	2900	6.0	(a)
	17	(a)	900	11	(a)	3300	5.9	(a)
	16	(a)	1000	9.4	(b)	3500	5.5	(b)
	16	(b)	1100	8.3	(a)	4300	4.4	(a)
410	14	(b)	1300	9.1	(a)	4600	4.8	(b)
530	12	(b)		8.1	(a)	5800	4.4	(b)
600	14	(a)	1400	8.1	(b)	8100	3.7	(b)
	13	(a)	2100	6.8	(b)	11000	3.1	(b)
	12	(a)	2300	7.0	(a)			

Experimental:

(a) Philbrick, et al., Phys. Rev. 181, 271 (1969).

(b) Frommhold, et al., Phys. Rev. 165, 44 (1968).

Table 8.7

Experimental values of the dissociative recombination coefficient of electrons and Ar_2^+ ions for $T_e = T_+ = T_g = 300°K$

Author	r_2 (10^{-7} cm^3/sec)	n (10^8 cm^{-3})	N (10^{17} cm^{-3})
(a)	6.7	1.1 to 710	2.9 to 11
(b)	6	2.1 to 53	4.5
(c)	8.5	0.64 to 26	6.4

Experimental:

(a) Oskam, et al., Phys. Rev. 132, 1445 (1963).

(b) Biondi, Phys. Rev. 129, 1181 (1963).

(c) Mehr, et al., Phys. Rev. 176, 322 (1968).

Table 8.8(a)

Temperature dependence of the dissociative recombination coefficient for Ar_2^+: $T_g = T_+ = 300°K$

T_e (°K)	r ($10^{-8} cm^3/sec$)	T_e (°K)	r ($10^{-8} cm^3/sec$)	T_e (°K)	r ($10^{-8} cm^3/sec$)
310	85	1500	28	4000	15
				5000	13
510	56	2000	22	6000	12
960	37				
1000	36	3000	17	7800	10
				8000	11
				8200	10
				9600	9.1
				10000	9.1

Experimental:
All data taken from Mehr, et al., Phys. Rev. 176, 322, (1968).

Table 8.8(b)

Temperature dependence of the dissociative recombination coefficient for Ar_2^+: $T_e = T_+ = T_g$

T_e (°K)	r ($10^{-8} cm^3/sec$)	T_e (°K)	r ($10^{-8} cm^3/sec$)	T_e (°K)	r ($10^{-8} cm^3/sec$)
550	44	790	31	1500	11
570	43	830	26	1600	9.4
580	41	850	25	1700	9.3
600	41	890	24	1800	7.5
610	41	960	20	1900	{7.6, 7.7
640	39	990	20		
670	41	1000	19	2100	6.7
690	40	1100	19	2200	5.8
700	35			2500	5.5
730	34	1300	13	2800	4.1
750	30			3000	4.1

Experimental:
All data taken from Cunningham, et al., Phys. Rev. 185, 98 (1969).

Table 8.9

Experimental value for the dissociative recombination coefficient for Kr_2^+ and Xe_2^+ for $T_e = T_+ = T_g = 300°K$

Gas	r ($10^{-7} cm^3/sec$)	n ($10^8 cm^{-3}$)	N ($10^{17} cm^{-3}$)
Kr	12	0.88 to 120	1.93 to 14.5
Xe	14	0.82 to 31	1.7 to 11.1

Experimental:
All data taken from Oskam, et al., Phys. Rev. 132, 1445 (1963).

Table 8.10

Temperature dependence of the dissociative recombination coefficient for Kr_2^+ for $T_e = T_+ = T_g$

T_e (°K)	r ($10^{-6}cm^3/sec$)	T_e (°K)	r ($10^{-6}cm^3/sec$)	T_e (°K)	r ($10^{-6}cm^3/sec$)
930	.44	1450	.24	1970	.15
970	.44	1520	.22	2070	.14
1070	.34	1560	.23	2110	.13
1130	.35	1620	.20	2250	.12
1180	.33	1770	.17	2400	.11
1260	.27	1800	.17	2610	.10
1350	.27	1870	.17	2800	.10
1400	.25	1900	.17		

Experimental:
All data taken from Cunningham, et al., J. Phys. B 5, 1773 (1972).

Table 8.11(a)

Theoretical radiative recombination coefficients for electrons with H^+ ions. Partial radiative recombination coefficients $r_2(p)$ to individual levels of principal quantum number p of the hydrogen atom.

Principal quantum No. \ T_e(°K)	250	500	1000	2000	1000	8000	16000	32000	64000
	$r_2(p)(10^{-14}cm^3/sec)$								
1	102	71.7	50.7	35.6	25.0	17.4	12.0	8.02	5.19
2	56.6	39.8	27.9	19.4	13.2	8.80	5.63	3.42	1.95
3	39.0	27.2	18.8	12.8	8.44	5.33	3.19	1.80	0.946
4	29.5	20.4	14.0	9.23	5.86	3.53	2.00	1.06	0.533
5	23.6	16.2	10.8	6.99	4.29	2.48	1.35	0.687	0.332
6	19.6	13.3	8.70	5.48	3.26	1.82	0.953	0.471	0.222
7	16.6	11.1	7.16	4.39	2.54	1.38	0.702	0.339	0.156
8	14.3	9.46	5.99	3.59	2.02	1.07	0.534	0.253	0.114
9	12.5	8.17	5.08	2.98	1.64	0.851	0.416	0.193	0.0866
10	11.1	7.13	4.36	2.51	1.35	0.688	0.331	0.152	0.0672
11	9.88	6.27	3.77	2.13	1.13	0.565	0.268	0.122	0.0533
12	8.87	5.56	3.29	1.83	0.953	0.471	0.221	0.0989	0.0430

Theoretical:
All data taken from Bates, et al., in Atomic and Molecular Processes (Academic Press, New York, (1962), p. 245.

Table 8.11(b)

Theoretical radiative recombination coefficients for electrons with H^+ ions. Total radiative recombination coefficient r_2 for electrons with H^+ ions.

Temperature °K	250	500	1000	2000	4000	8000	16000	32000	64000
$r_2(10^{-13}cm^3/sec)$	48.4	31.2	19.9	12.6	7.85	4.83	2.93	1.73	1.00

Theoretical:
All data taken from Bates, et al., in Atomic and Molecular Processes (Academic Press, New York, (1962), p. 245.

Table 8.12(a)

Theoretical collisional-radiative decay coefficient g_c [see eq. (24)] for H^+ ions in optically thin plasmas.
Theoretical collisional-radiative recombination coefficient r_c.

T_e (°K)	50 (1)	100 (1)	150 (1)	200 (1)	250 (2)	500 (2)	1000 (2)	2000 (2)	4000 (2)	8000 (2)	16000 (2)	32000 (2)
n (cm^{-3})	r_c (10^{-11} cm^3/sec)											
limit $n \to 0$					0.48	0.31	0.20	0.13	0.079	0.048	0.029	0.017
10^2	2.3	1.1	0.80	0.65								
10^3	3.4	1.4	0.90	0.70								
10^4	6.8	1.9	1.1	0.82								
10^5	21	3.5	1.7	1.1								
10^5	95	9.5	3.4	1.9								
10^7	700	39	10	4.5								
10^8	6600	250	47	17	8.8	1.4	0.41	0.18	0.092	0.051	0.030	0.018
10^9	65000	2300	350	96	40	3.8	0.75	0.25	0.10	0.053	0.030	0.018
10^{10}		23000	3300	840	280	16	1.9	0.41	0.14	0.061	0.032	0.018
10^{11}			32000	8000	2700	100	6.9	0.91	0.22	0.081	0.034	0.018
10^{12}					26000	900	39	2.9	0.44	0.12	0.043	0.020
10^{13}					260000	8900	310	14	1.2	0.21	0.062	0.024
10^{14}					2600000	88000	2900	98	5.1	0.51	0.10	0.031
10^{15}						880000	29000	870	27	1.7	0.23	0.049
10^{16}							290000	8500	230	8.4	0.50	0.073
10^{17}								84000	2100	34	1.4	0.18
limit $n \to \infty$ *					$2.6^{-8}n$	$8.8^{-10}n$	$2.9^{-11}n$	$8.4^{-13}n$	$1.9^{-14}n$	$2.4^{-16}n$	$9.1^{-18}n$	$1.1^{-18}n$

*In this row $2.6^{-8}n$ etc = $2.6 \times 10^{-8}n$ etc and gives the value of r_c in units of ($10^{-11}cm^3$/sec).

Theoretical:

(1) Bates, et al., Proc. Phys. Soc. (London) 83, 43 (1964).
(2) Bates, et al., Proc. Roy. Soc. (London) Ser A 257, 297 (1962).

Table 8.12(b)

Theoretical collisional-radiative decay coefficient g_c [see eq. (24)] for H^+ ions in optically thin plasmas. Collisional-radiative ionization coefficient i_c.

T_e (°K) / n (cm^{-3})	4000	8000	16000	32000
		i_c (cm^3/sec)		
limit $n \to 0$	1.4×10^{-26}	9.7×10^{-18}	3.4×10^{-13}	8.2×10^{-11}
10^8	1.6×10^{-26}	1.1×10^{-17}	3.6×10^{-13}	8.4×10^{-11}
10^9	1.8×10^{-26}	1.2×10^{-17}	3.8×10^{-13}	8.8×10^{-11}
10^{10}	2.7×10^{-26}	1.4×10^{-17}	4.2×10^{-13}	9.2×10^{-11}
10^{11}	4.5×10^{-26}	1.9×10^{-17}	4.9×10^{-13}	1.0×10^{-10}
10^{12}	1.0×10^{-25}	3.0×10^{-17}	6.5×10^{-13}	1.2×10^{-10}
10^{13}	3.6×10^{-25}	6.8×10^{-17}	1.1×10^{-12}	1.7×10^{-10}
10^{14}	2.2×10^{-24}	2.3×10^{-16}	2.5×10^{-12}	2.9×10^{-10}
10^{15}	1.8×10^{-23}	1.3×10^{-15}	8.6×10^{-12}	6.9×10^{-10}
10^{16}	1.5×10^{-22}	5.9×10^{-15}	1.9×10^{-11}	1.0×10^{-9}
10^{17}	5.8×10^{-22}	1.0×10^{-14}	2.3×10^{-11}	1.1×10^{-9}
limit $n \to \infty$	8.3×10^{-22}	1.1×10^{-14}	2.3×10^{-11}	1.1×10^{-9}

Theoretical:
All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser A 267, 297 (1962).

Table 8.13(a)

Theoretical collisional-radiative recombination coefficients for H^+ ions in optically thick plasmas. Recombination coefficient r_c for plasma optically thick to the lines of the Lyman series.

T_e (°K) / n (cm^{-3})	250	500	1000	3000	4000	8000	16000	32000	64000
				r_c ($10^{-12}cm^3$/sec)					
limit $n \to 0$	4.8	3.1	2.0	1.3	0.79	0.46	0.19	0.093	0.055
10^8	79	12	3.7	1.7	0.89	0.48	0.19	0.093	0.055
10^9	380	34	6.4	2.2	1.0	0.50	0.18	0.092	0.055
10^{10}	2900	150	16	3.5	1.2	0.54	0.18	0.091	0.055
10^{11}	27000	1000	61	7.5	1.8	0.60	0.18	0.089	0.054
10^{12}	260000	8900	360	25	3.4	0.68	0.16	0.086	0.053
10^{13}		88000	3000	130	9.2	0.66	0.14	0.083	0.053
10^{14}			29000	940	35	0.81	0.14	0.083	0.053
10^{15}				8500	210	3.0	0.23	0.093	0.055
10^{16}					1900	25	1.1	0.20	0.079
limit $n \to \infty$*	$2.6^{-7}n$	$8.8^{-9}n$	$2.9^{-10}n$	$8.4^{-12}n$	$1.9^{-13}n$	$2.4^{-15}n$	$9.1^{-17}n$	$1.1^{-17}n$	$2.7^{-18}n$

*In this row $2.6^{-7}n$ etc = $2.6 \times 10^{-7}n$ etc and gives the value of r_c in units of ($10^{-12}cm^3$/sec).

Theoretical:
All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser A 270, 155 (1962).

Table 8.13(b)

Theoretical collisional-radiative recombination coefficients for H^+ ions in optically thick plasmas. Recombination coefficient r_c for plasma optically thick to the lines of the Lyman series and the Lyman continuum.

T_e(°K) / n(cm^{-3})	250	500	1000	2000	4000	8000	16000	32000	64000
	r_c($10^{-12}cm^3$/sec)								
limit n→0	3.8	2.4	1.5	0.94	0.54	0.29	0.07	0.013	0.003
10^8	78	11	3.2	1.3	0.64	0.31	0.07	0.013	0.003
10^9	380	33	5.9	1.8	0.75	0.33	0.06	0.012	0.003
10^{10}	2900	150	15	3.1	1.0	0.37	0.06	0.011	0.003
10^{11}	27000	1000	60	7.1	1.6	0.43	0.06	0.009	0.002
10^{12}	260000	8900	360	25	3.2	0.51	0.04	0.006	0.001
10^{13}		88000	3000	130	9.0	0.49	0.02	0.003	0.001
10^{14}			29000	940	35	0.64	0.02	0.003	0.001
10^{15}				8500	210	2.8	0.11	0.013	0.003
10^{16}					1900	2.5	1.0	0.12	0.027

Theoretical:
All data calculated from Bates, et al., Proc. Roy. Soc. (London) Ser. A 270, 155 (1962).

Table 8.13(c)

Theoretical collisional-radiative recombination coefficients for H^+ ions in optically thick plasmas. Recombination coefficient r_c for plasma optically thick to lines of all series.

T_e(°K) / n(cm^{-3})	250	500	1000	2000	4000	8000	16000	32000	64000
	r_c($10^{-12}cm^3$/sec)								
limit n→0	3.4	2.1	1.3	0.75	0.40	0.19	0.12	0.081	0.052
10^8	29	3.0	1.3	0.75	0.40	0.19	0.12	0.081	0.052
10^9	260	11	1.6	0.76	0.40	0.19	0.12	0.081	0.052
10^{10}	2600	90	4.2	0.83	0.40	0.19	0.12	0.081	0.052
10^{11}	26000	880	30	1.6	0.42	0.19	0.12	0.081	0.052
10^{12}	260000	8800	290	9.2	0.60	0.19	0.12	0.081	0.052
10^{13}		88000	2900	85	2.3	0.21	0.12	0.081	0.052
10^{14}			29000	840	19	0.43	0.13	0.082	0.053
10^{15}				8400	190	2.6	0.21	0.092	0.055
10^{16}					1900	240	1.0	0.19	0.079

Theoretical:
All data calculated from Bates, et al., Proc. Roy. Soc. (London) Ser. A 270, 155 (1962).

Table 8.13(d)

Theoretical collisional-radiative recombination coefficients for H^+ ions in optically thick plasmas. Recombination coefficient r_c for plasma optically thick to lines of all series and the Lyman continuum.

T_e(°K)	250	500	1000	2000	4000	8000	16000	32000	64000
n(cm^{-3})				r_c(10^{-12}cm^3/sec)					
limit n→0	2.4	1.4	0.77	0.40	0.15	0.017	0.0024	0.00063	0.00024
10^8	28	2.3	0.80	0.40	0.15	0.017	0.0024	0.00063	0.00024
10^9	260	10	1.1	0.41	0.15	0.017	0.0024	0.00063	0.00024
10^{10}	2600	89	3.7	0.48	0.15	0.017	0.0024	0.00063	0.00024
10^{11}	26000	880	30	1.2	0.17	0.017	0.0024	0.00063	0.00024
10^{12}	260000	8800	290	8.8	0.34	0.019	0.0025	0.00064	0.00024
10^{13}		88000	2900	84	2.0	0.041	0.0033	0.00074	0.00027
10^{14}			29000	840	19	0.26	0.012	0.0017	0.00051
10^{15}				8400	190	2.4	0.093	0.012	0.0029
10^{16}					1900	2.4	0.91	0.11	0.027

Theoretical:
All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser. A 270, 155 (1962).

Table 8.14 (a)

Collisional-radiative recombination coefficient r_c for a magnetically confined hydrogen plasma optically thick to the lines of the Lyman series at T_g = 250°K

$n(cm^{-3})$	N/n	10^{-1}	10^{0}	10^{1}	10^{2}	10^{3}	10^{4}
10^{9}	T_e*	1.2	0.64	0.39	0.29	0.26	0.25
	T_i*	1.2	0.64	0.39	0.29	0.26	0.25
	r_c*	0.49	1.7	7.9	22	32	35
10^{10}	T_e	1.5	0.83	0.51	0.36	0.3	0.27
	T_i	1.5	0.83	0.51	0.35	0.28	0.25
	r_c	0.63	2.7	13	55	140	220
10^{11}	T_e	1.9	1.1	0.71	0.5	0.40	0.35
	T_i	1.9	1.1	0.69	0.47	0.32	0.26
	r_c	0.93	4.5	24	98	270	520
10^{12}	T_e	2.4	1.5	1.0	0.74	0.59	0.50
	T_i	2.4	1.5	0.96	0.61	0.35	0.26
	r_c	1.4	7.8	38	150	410	890
10^{13}	T_e	3.2	2.1	1.4	1.1	0.92	0.77
	T_i	3.2	2.0	1.3	0.76	0.36	0.26
	r_c	2.1	11	56	180	450	1000
10^{14}	T_e	4.1	2.9	2.1	1.7	1.4	1.2
	T_i	4.1	2.8	1.	0.79	0.35	0.26
	r_c	3.0	16	70	220	460	1300
10^{15}	T_e	5.4	4.0	3.1	2.6	2.22	1.7
	T_i	5.3	3.7	2.0	0.76	0.33	0.26
	r_c	3.5	21	88	220	470	1700

*T_e in (10^3°K); T_i in (10^3°K); r_c in ($10^{-11} cm^3$/sec) throughout this table.

Theoretical:
All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser. A 279, 10 (1964).

Table 8.14(b)

Collisional-radiative recombination coefficient r_c for a magnetically confined hydrogen plasma optically thick to the lines of the Lyman series at T_g = 1000°K

$n(cm^{-3})$	N/n	10^{-1}	10^{0}	10^{1}	10^{2}	10^{3}	10^{4}
10^9	T_e*	1.6	1.1	1.0	1.0	1.0	1.0
	T_i*	1.6	1.1	1.0	1.0	1.0	1.0
	r_c*	0.32	0.56	0.65	0.65	0.65	0.65
10^{10}	T_e	1.8	1.2	1.0	1.0	1.0	1.0
	T_i	1.8	1.2	1.0	1.0	1.0	1.0
	r_c	0.46	1.1	1.5	1.6	1.6	1.6
10^{11}	T_e	2.1	1.4	1.1	1.0	1.0	1.0
	T_i	2.1	1.4	1.1	1.0	1.0	1.0
	r_c	0.69	2.3	4.8	5.9	6.0	6.0
10^{12}	T_e	2.6	1.7	1.3	1.1	1.0	1.0
	T_i	2.6	1.7	1.3	1.0	1.0	1.0
	r_c	1.1	4.6	13	28	32	35
10^{13}	T_e	3.4	2.3	1.6	1.3	1.2	1.1
	T_i	3.4	2.3	1.5	1.1	1.0	1.0
	r_c	1.8	8.1	32	76	120	170
10^{14}	T_e	4.3	3.1	2.2	1.9	1.7	1.4
	T_i	4.3	3.0	1.9	1.2	1.0	1.0
	r_c	2.5	12	55	130	230	510
10^{15}	T_e	5.6	4.1	3.2	2.8	2.4	1.9
	T_i	5.6	3.8	2.3	1.3	1.0	1.0
	r_c	3.2	18	76	160	320	1100

*T_e in (10^3°K), T_i in (10^3°K); r_c in ($10^{-11}cm^3$/sec) throughout this table.

Theoretical:
All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser. A 279, 10 (1964).

Table 8.14(c)

Collisional-radiative recombination coefficient r_c for a magnetically confined hydrogen plasma optically thick to the lines of the Lyman series at T_g = 4000°K

$n(cm^{-3})$	N/n	10^{-1}	10^{0}	10^{1}	10^{2}	10^{3}	10^{4}
10^9	T_e*	4.1	4.0	4.0	4.0	4.0	4.0
	T_i*	4.1	4.0	4.0	4.0	4.0	4.0
	r_c*	0.098	0.10	0.10	0.10	0.10	0.10
10^{10}	T_e	4.1	4.0	4.0	4.0	4.0	4.0
	T_i	4.1	4.0	4.0	4.0	4.0	4.0
	r_c	0.12	0.12	0.12	0.12	0.12	0.12
10^{11}	T_e	4.1	4.0	4.0	4.0	4.0	4.0
	T_i	4.1	4.0	4.0	4.0	4.0	4.0
	r_c	0.17	0.18	0.18	0.18	0.18	0.18
10^{12}	T_e	4.3	4.0	4.0	4.0	4.0	4.0
	T_i	4.3	4.0	4.0	4.0	4.0	4.0
	r_c	0.29	0.34	0.35	0.35	0.35	0.35
10^{13}	T_e	4.5	4.1	4.0	4.0	4.0	4.0
	T_i	4.5	4.1	4.0	4.0	4.0	4.0
	r_c	0.58	0.85	0.93	0.39	0.93	0.93
10^{14}	T_e	4.9	4.3	4.1	4.0	4.0	4.0
	T_i	4.9	4.2	4.0	4.0	4.0	4.0
	r_c	1.2	2.5	3.2	3.4	3.5	3.5
10^{15}	T_e	5.9	4.8	4.3	4.2	4.1	4.0
	T_i	5.9	4.7	4.1	4.0	4.0	4.0
	r_c	2.1	7.6	13	15	18	21

*T_e in (10^3°K); T_i in (10^3°K); r_c in ($10^{-11}cm^3$/sec) throughout this table.

Theoretical:
All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser. A 279, 10 (1964).

Table 8.15(a)

Collisional-radiative recombination coefficient r_c for a magnetically confined optically thin hydrogen plasma at T_g = 250°K

$n(cm^{-3})$	N/n	10^{-1}	10^{0}	10^{1}	10^{2}	10^{3}	10^{4}
10^8	T_e*	0.36	0.27	0.25	0.25	0.25	0.25
	T_i*	0.36	0.27	0.25	0.25	0.25	0.25
	r_c*	3.3	6.8	8.5	8.7	8.7	8.7
10^9	T_e	0.51	0.36	0.26	0.25	0.25	0.25
	T_i	0.51	0.36	0.26	0.25	0.25	0.25
	r_c	3.5	10	32	38	40	40
10^{10}	T_e	0.72	0.48	0.35	0.28	0.26	0.25
	T_i	0.72	0.48	0.35	0.28	0.26	0.25
	r_c	4.9	18	71	180	260	280
10^{11}	T_e	0.98	0.67	0.48	0.37	0.31	0.29
	T_i	0.98	0.67	0.48	0.36	0.28	0.26
	r_c	7.4	29	120	430	930	1400
10^{12}	T_e	1.4	0.96	0.68	0.52	0.42	0.38
	T_i	1.4	0.95	0.67	0.47	0.32	0.26
	r_c	9.3	47	210	760	2100	3400
10^{13}	T_e	2.2	1.4	1.0	0.77	0.63	0.57
	T_i	2.2	1.4	0.95	0.60	0.34	0.26
	r_c	10	59	310	1100	2800	4900
10^{14}	T_e	3.3	2.2	1.6	1.2	1.1	0.88
	T_i	3.3	2.1	1.4	0.7	0.34	0.26
	r_c	11	69	320	1200	2100	5600
10^{15}	T_e	4.9	3.4	2.4	2.0	1.8	1.4
	T_i	4.8	3.1	1.8	0.72	0.32	0.26
	r_c	11	72	330	850	1700	6300

*T_e in (10^3°K); T_i in (10^3°K); r_c in ($10^{-11}cm^3$/sec) throughout this table.

Theoretical:

All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser. A 279, 10 (1964).

Table 8.15(b)

Collisional-radiative recombination coefficient r_c for a magnetically confined optically thin hydrogen plasma at T_g = 1000°K

$n(cm^{-3})$	N/n	10^{-1}	10^{0}	10^{1}	10^{2}	10^{3}	10^{4}
10^8	T_e*	1.0	1.0	1.0	1.0	1.0	1.0
	T_i*	1.0	1.0	1.0	1.0	1.0	1.0
	r_c*	0.42	0.42	0.42	0.42	0.42	0.42
10^9	T_e	1.0	1.0	1.0	1.0	1.0	1.0
	T_i	1.0	1.0	1.0	1.0	1.0	1.0
	r_c	0.72	0.76	0.76	0.76	0.76	0.76
10^{10}	T_e	1.1	1.0	1.0	1.0	1.0	1.0
	T_i	1.1	1.0	1.0	1.0	1.0	1.0
	r_c	1.6	1.9	1.9	1.9	1.9	1.9
10^{11}	T_e	1.2	1.0	1.0	1.0	1.0	1.0
	T_i	1.2	1.0	1.0	1.0	1.0	1.0
	r_c	3.5	6.0	6.9	6.9	6.9	6.9
10^{12}	T_e	1.6	1.2	1.0	1.0	1.0	1.0
	T_i	1.6	1.2	1.0	1.0	1.0	1.0
	r_c	6.3	17	32	38	38	38
10^{13}	T_e	2.3	1.6	1.2	1.1	1.0	1.0
	T_i	2.3	1.6	1.2	1.0	1.0	1.0
	r_c	7.9	35	100	190	250	270
10^{14}	T_e	3.4	2.3	1.7	1.4	1.3	1.2
	T_i	3.4	2.3	1.6	1.1	1.0	1.0
	r_c	9.5	52	220	550	830	1200
10^{15}	T_e	4.9	3.4	2.6	2.2	2.0	1.6
	T_i	4.9	3.3	2.0	1.2	1.0	1.0
	r_c	11	69	260	580	1000	3000

*T_e in (10^3°K); T_i in (10^3°K); r_c in (10^{-11} cm^3/sec) throughout this table.

Theoretical:
All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser. A 279, 10 (1964).

Table 8.15(c)

Collisional-radiative recombination coefficient r_c for a magnetically confined optically thin hydrogen plasma at T_g = 4000°K

n(cm^{-3})	N/n	10^{-1}	10^{0}	10^{1}	10^{2}	10^{3}	10^{4}
10^8	T_e*	4.0	4.0	4.0	4.0	4.0	4.0
	T_i*	4.0	4.0	4.0	4.0	4.0	4.0
	r_c*	0.096	0.096	0.096	0.096	0.096	0.096
10^9	T_e	4.0	4.0	4.0	4.0	4.0	4.0
	T_i	4.0	4.0	4.0	4.0	4.0	4.0
	r_c	0.11	0.11	0.11	0.11	0.11	0.11
10^{10}	T_e	4.0	4.0	4.0	4.0	4.0	4.0
	T_i	4.0	4.0	4.0	4.0	4.0	4.0
	r_c	0.14	0.14	0.14	0.14	0.14	0.14
10^{11}	T_e	4.0	4.0	4.0	4.0	4.0	4.0
	T_i	4.0	4.0	4.0	4.0	4.0	4.0
	r_c	0.22	0.22	0.22	0.22	0.22	0.22
10^{12}	T_e	4.0	4.0	4.0	4.0	4.0	4.0
	T_i	4.0	4.0	4.0	4.0	4.0	4.0
	r_c	0.44	0.45	0.45	0.45	0.45	0.45
10^{13}	T_e	4.1	4.0	4.0	4.0	4.0	4.0
	T_i	4.1	4.0	4.0	4.0	4.0	4.0
	r_c	1.1	1.2	1.2	1.2	1.2	1.2
10^{14}	T_e	4.6	4.1	4.0	4.0	4.0	4.0
	T_i	4.6	4.1	4.0	4.0	4.0	4.0
	r_c	3.1	4.8	5.1	5.1	5.1	5.1
10^{15}	T_e	5.8	4.7	4.2	4.1	4.0	4.0
	T_i	5.8	4.6	4.1	4.0	4.0	4.0
	r_c	5.8	13	23	26	26	26

*T_e in (10^3°K); T_i in (10^3°K); r_c in ($10^{-11}cm^3$/sec) throughout this table.

Theoretical:

All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser. A 279, 10 (1964).

Table 8.16(a)

Upper limit of the collisional-radiative recombination coefficient r_c for a hydrogen plasma optically thick to the Lyman series and not confined by a magnetic field: $T_g = T_i = 250°K$

$n(cm^{-3})$	N/n	10^0	10^1	10^2	10^3	10^4
10^9	T_e*	2.5	2.5	2.5	2.5	2.5
	r_c*	3.6	3.6	3.6	3.6	3.6
10^{10}	T_e	2.8	2.8	2.8	2.8	2.7
	r_c	18	18	18	18	22
10^{11}	T_e	3.8	3.8	3.8	3.7	3.5
	r_c	36	36	36	38	52
10^{12}	T_e	5.7	5.7	5.6	5.5	5.0
	r_c	49	49	50	58	90
10^{13}	T_e	9.2	9.2	9.1	8.9	7.7
	r_c	44	44	46	51	100
10^{14}	T_e	16	15	15	14	12
	r_c	32	33	34	50	130
10^{15}	T_e	26	25	25	22	17
	r_c	24	25	28	50	180

*T_e in (10^2°K); r_c in ($10^{-10}cm^3$/sec) throughout this table.

Theoretical:

All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser. A 279, 10 (1964).

Table 8.16(b)

Upper limit of the collisional-radiative recombination coefficient r_c for a hydrogen plasma optically thick to the Lyman series and not confined by a magnetic field: $T_g = T_i = 1000°K$

$n(cm^{-3})$	N/n	10^0	10^1	10^2	10^3	10^4
10^9	T_e*	10	10	10	10	10
	r_c*	0.065	0.065	0.065	0.065	0.065
10^{10}	T_e	10	10	10	10	10
	r_c	0.16	0.16	0.16	0.16	0.16
10^{11}	T_e	10	10	10	10	10
	r_c	0.60	0.60	0.60	0.60	0.60
10^{12}	T_e	10	10	10	10	10
	r_c	3.2	3.2	3.2	3.2	3.5
10^{13}	T_e	12	12	12	12	11
	r_c	10	10	10	12	17
10^{14}	T_e	18	18	18	16	14
	r_c	16	16	17	24	51
10^{15}	T_e	27	27	27	24	19
	r_c	16	16	18	32	110

*T_e in (10^2°K); r_c in (10^{-10} cm^3/sec) throughout this table.

Theoretical:

All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser. A 279, 10 (1964).

Table 8.17(a)

Upper limit of collisional-radiative recombination coefficient for an optically thin hydrogen plasma not confined by a magnetic field: $T_g = T_i = 250$°K

$n(cm^{-3})$	N/n	10^0	10^1	10^2	10^3	10^4
10^8	T_e*	2.5	2.5	2.5	2.5	2.5
	r_c*	0.89	0.89	0.89	0.89	0.89
10^9	T_e	2.5	2.5	2.5	2.5	2.5
	r_c	4.1	4.1	4.1	4.1	4.1
10^{10}	T_e	2.5	2.5	2.5	2.5	2.5
	r_c	28	28	28	28	28
10^{11}	T_e	2.9	2.9	2.9	2.9	2.8
	r_c	140	140	140	140	150
10^{12}	T_e	3.9	3.9	3.9	3.9	3.7
	r_c	290	290	290	300	370
10^{13}	T_e	6.2	6.2	6.2	6.1	5.7
	r_c	320	320	320	330	490
10^{14}	T_e	11	11	11	10	8.8
	r_c	200	200	200	250	560
10^{15}	T_e	20	20	19	18	14
	r_c	100	100	110	180	630

*T_e in (10^2°K); r_c in ($10^{-10} cm^3/sec$) throughout this table.

Theoretical:
All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser. A 279, 10 (1964).

Table 8.17(b)

Upper limit of collisional-radiative recombination coefficient for an optically thin hydrogen plasma not confined by a magnetic field: $T_g = T_i = 1000°K$

$n(cm^{-3})$	N/n	10^0	10^1	10^2	10^3	10^4
10^8	T_e*	10	10	10	10	10
	r_c*	0.043	0.043	0.043	0.043	0.043
10^9	T_e	10	10	10	10	10
	r_c	0.078	0.078	0.078	0.078	0.078
10^{10}	T_e	10	10	10	10	10
	r_c	0.19	0.19	0.19	0.19	0.19
10^{11}	T_e	10	10	10	10	10
	r_c	0.69	0.69	0.69	0.69	0.69
10^{12}	T_e	10	10	10	10	10
	r_c	3.9	3.9	3.9	3.9	3.9
10^{13}	T_e	11	11	11	10	10
	r_c	24	24	24	25	28
10^{14}	T_e	13	13	13	13	12
	r_c	69	69	69	85	130
10^{15}	T_e	22	22	22	20	16
	r_c	65	65	65	100	320

*T_e in (10^2°K); r_c in ($10^{-10} cm^3/sec$) throughout this table.

Theoretical:

All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser. A 279, 10 (1964).

Table 8.18

Theoretical values for dielectronic and radiative recombination coefficients for $N^+(3p)$

T_e(°K)	$r(10^{-13} cm^3/sec)$ dielectronic	$r(10^{-13} cm^3/sec)$ radiative
1000	1.0	13
2000	1.6	7.8
3000	1.5	5.6

Theoretical:
All data taken from Bates, Planetary Space Sci. 9, 77 (1962).

Table 8.19

Theoretical values of the collisional-radiative recombination coefficient for the reaction $Z^+ + e + N_2 \rightarrow Z + N_2$ when the mass of the ion Z^+ is taken as 28 e.m.u. $T = T_e = T_i = T_g$

T(°K)	125	250	500	1000	2000
$N(cm^{-3})$			$r_c'(cm^3/sec)$		
1.0×10^{17}	2.8×10^{-10}	7.7×10^{-11}	2.7×10^{-11}	1.2×10^{-11}	5.5×10^{-12}
1.0×10^{18}	2.7×10^{-9}	7.5×10^{-10}	2.6×10^{-10}	1.1×10^{-10}	5.3×10^{-11}
1.0×10^{19}	2.8×10^{-8}	7.6×10^{-9}	2.6×10^{-9}	1.1×10^{-9}	5.3×10^{-10}
1.0×10^{20}	2.8×10^{-7}	7.3×10^{-8}	2.6×10^{-8}	1.1×10^{-8}	5.3×10^{-9}
1.0×10^{21}		7.5×10^{-7}	2.6×10^{-7}	1.1×10^{-7}	5.1×10^{-8}

N is the number density of nitrogen molecules

r_c' is the collisional radiative recombination coefficient less the radiative recombination coefficient.

Theoretical:
All data taken from Bates, et al., Proc. Roy. Soc. (London) Ser A 320, 437 (1971).

Table 8.20

The dissociative recombination coefficient for O_2^+ ions for $T_e = T_i = T_g \approx 295°K$

$r_2(10^{-7}cm^3sec^{-1})$	1.95 (a)	2.2 (b)	2.1 (c)	1.9±0.5 (d)	1.1 (1)	2.8 (2)
$n(10^{10}cm^{-3})$	0.05 to 1	0.02 to 1	0.04 to 10	0.1 to 1		
$N(O_2)(10^{10}cm^{-3})$	0.16 to 3.9×10^4	0.98 to 2.6×10^4	6.55×10^4	0.17 to 3.5×10^4		
$N(Ne)(cm^{-3})$	6.55×10^{17}	5.9×10^{17}	5.9×10^{17}	$\approx3.28\times10^{17}$	--------	----------
$N(Kr)(cm^{-3})$	--------	3.28×10^{16}	--------	---------	--------	----------
$N(He)(cm^{-3})$	--------	--------	3.28×10^{16}	---------	6.55×10^{16}	----------
$N(Ar)(cm^{-3})$	--------	--------	--------	---------	--------	3.18×10^{16}

Experimental:

(a) Mehr, et al., Phys. Rev., 181, 264 (1969).
(b) Kasner, et al., Phys. Rev. 174, 139 (1968).
(c) Smith, et al., Planetary Space Sci. 16, 1177 (1968).
(d) Mahdavi, et al., J. Phys. B 4, 1726 (1971).

Theoretical:

(1) Warke, Phys. Rev. 144, 120 (1966).
(2) Chan, J. Chem. Phys. 49, 2533 (1968).

Table 8.21

Theoretical values of the radiative and dielectronic recombination coefficient for electons and O^+

T_e(°K)	$r(10^{-12}cm^3sec^{-1})$ dielectronic (2)	$r(10^{-12}cm^3sec^{-1})$ radiative (1)
250		3.69
500		2.39
1000	0.0043	1.48
2000	0.025	0.89
3000	0.034	
4000		0.53
8000		0.33

Theoretical:

(1) Massey, et al., Rept. Progr. Phys. 9, 62 (1943).
(2) Bates, Planetary Space Sci. 9, 77 (1962).

Table 8.22

Experimental values of the dissociative recombination coefficient r_2 for NO^+ ions at room temperature

$r_2(10^{-7}cm^3sec^{-1})$	$4.6^{+0.5}_{-1.3}$ (a)	$4.1^{+0.3}_{-0.2}$ (b)	3.4 ± 0.6 (c)
$T_e = T_i = T_g$(°K)	298	300	300
$n(10^8cm^{-3})$	~35	~2 to 20	~10 to 100
$N(NO)(cm^{-3})$	1.9 to 3.9 × 10^{13}	1.9 to 16 × 10^{14}	0.28 to 2.8 × 10^{14}
$N(Ne)(cm^{-3})$	4.5 to 5.1 × 10^{18}	7.8 to 27 × 10^{16}	--------
$N(Ar)(cm^{-3})$	--------	-------	3.5 × 10^{16}

Experimental:

(a) Gunton, et al., Phys. Rev. 140, A756 (1965).
(b) Weller, et al., Phys. Rev. 172, 198 (1968).
(c) Mahdavi, et al., J. Phys. B 4, 1726 (1971).

4. Scope and Arrangement of Biblography

The intention is to include, in the Bibliography, references to published papers which contain original experimental or theoretical data on the eight properties of electron swarms listed in the first paragraph of the Introduction. By our definition of an electron swarm as a low number density electron gas in a neutral gas of considerably greater number density, papers concerned with very highly ionized gases are excluded. The scope has, however, been widened somewhat to include papers concerned with conductivity and energy distributions not only for swarms but also for the region lying between that of swarms and very highly ionized gases, in which interactions of electrons both with neutral and with charged particles are of importance; references to papers concerned with collisional radiative recombination are also included.

The Bibliography is arranged in two parts, sections 5.1 and 5.2; the first lists abbreviated references arranged by type of data, and the second lists full references in order of arbitrary file numbers.

In section 5.1, the abbreviated references consist of the arbitrary file number, the first author and the last two digits of the year of publication. In the case of references to experimental papers an indication of the principle of the method used to obtain the data is also given after the reference, where more than one well-recognized method is available. If only one method has been used, as for example in the case of D_T/μ where the Townsend method is the only one available to date, no method is indicated. Occasionally methods fall outside the broad categories allocated and in these cases also method is omitted. These abbreviated references are ordered as follows:

A. Coefficient (e.g., drift velocity, diffusion coefficient, etc.)

B. Experimental or theoretical

C. Gas

Most of the listings under this third heading are of neutral gases in the following order:

(1) monatomic gases in order of atomic number;
(2) diatomic gases with molecules composed of two identical atoms in order of atomic number;
(3) other molecular gases, except hydrocarbons, grouped in order of the atomic number of the first atom, and ordered within the group in order of the multiplicity of the first atom;
(4) hydrocarbons grouped under the multiplicity of the carbon atom and ordered within groups in order of multiplicity of the hydrogen atom;
(5) organic compounds of hydrogen and carbon plus one or more other atoms, the symbols for which do not extend to more than nine characters, which was the field width available;
(6) organic compounds not containing hydrogen, the symbols for which do not extend to more than nine characters;
(7) organic; organic compounds, the symbols for which exceed nine characters; in these cases the symbols of the compounds used are given after the titles in section 5.2;
(8) air; and
(9) mixture; in this case the mixtures used are indicated after the titles in section 5.2.

In the case of recombination coefficient, however, the nature of the ion involved is indicated in the following cases:

(a) theoretical papers in which computations are made for a specific ion species, and (b) experimental papers if, and only if, a positive identification of the species is made mass spectrometrically. The ions are listed in order of increasing atomic number immediately following the parent gas (e.g., H_1^+, H_2^+, H_3^+ follow H_2, in that order). Ionization is represented by a superscript which follows the symbol and indicates the degree of ionization (e.g., H^+, H_2^+, and H_2^{++} are indicated by H^{+1}, H_2^{+1} and by H_2^{+2}, respectively).

D. File number.

5. Bibliography

5.1. Abbreviated References, Arranged by Type of Data

Drift Velocity (Experimental)

He	201	Townsend, 23	Magnetic Deflection
	530	Pack, 61	Time of Flight
	701	Stern, 63	
	888	Phelps, 60	Time of Flight
	1237	Hornbeck, 51	Time of Flight
	1387	Nielsen, 36	Time of Flight
	1434	Lowke, 62	Time of Flight
	1489	Crompton, 65	Time of Flight
	1489	Crompton, 65	Magnetic Deflection
	1623	Bowe, 60	Time of Flight
	1714	Levine, 62	Time of Flight
	1730	Levine, 65	Time of Flight
	2133	Wahlin, 26	Time of Flight
	2135	Loeb, 24	Time of Flight
	2164	Anderson, 64	
	2266	Levine, 67	Time of Flight
	2343	Meisel, 65	
	2433	Crompton, 67	Time of Flight
	2433	Crompton, 67	Magnetic Deflection
	3313	Wagner, 67	Time of Flight
	4023	Takayama, 62	
	4055	Grunberg, 69	Time of Flight
	4058	Grunberg, 68	Time of Flight
	4355	Crompton, 70	Time of Flight
	4913	Crompton, 71	Time of Flight
	5960	Errett, 51	
Ne	530	Pack, 61	Time of Flight
	1387	Nielsen, 36	Time of Flight
	1623	Bowe, 60	Time of Flight
	2164	Anderson, 64	
	2399	English, 53	Time of Flight
	4023	Takayama, 62	
	4862	Robertson, 72	Time of Flight
	5780	Sugawara, 70	
Ar	197	Townsend, 22	Magnetic Deflection
	199	Townsend, 22	Magnetic Deflection
	530	Pack, 61	Time of Flight
	732	Bortner, 57	Time of Flight
	1133	Caren, 63	Time of Flight
	1333	Colli, 52	Time of Flight
	1387	Nielsen, 36	Time of Flight
	1565	Christophorou, 65	Time of Flight
	1623	Bowe, 60	Time of Flight
	1752	Wahlin, 31	
	1811	Zelby, 66	

Drift Velocity (Experimental)—*Continued*

	2042	Kirshner, 52	Time of Flight
	2055	Klema, 50	Time of Flight
	2153	Jager, 62	
	2164	Anderson, 64	
	2261	Nagy, 60	Time of Flight
	2262	Herreng, 42	Time of Flight
	2264	Herreng, 43	Time of Flight
	2343	Meisel, 65	
	2357	Vorobev, 60	Time of Flight
	2399	English, 53	Time of Flight
	2542	Hudson, 46	Time of Flight
	2821	Colli, 51	
	2920	Levine, 64	Time of Flight
	3313	Wagner, 67	Time of Flight
	3480	Konjevic, 68	
	3896	Hearne, 68	
	4058	Grunberg, 68	Time of Flight
	4944	Brambring, 64	Time of Flight
	4971	Wagner, 64	Time of Flight
	5188	Allen, 70	Time of Flight
	5295	Carmichael, 72	
	5960	Errett, 51	
Kr	439	Pack, 62	Time of Flight
	1623	Bowe, 60	Time of Flight
	2399	English, 53	Time of Flight
Xe	439	Pack, 62	Time of Flight
	1623	Bowe, 60	Time of Flight
	2399	English, 53	Time of Flight
	4971	Wagner, 64	Time of Flight
Cs	764	Boeckner, 33	
	1154	Chanin, 64	Time of Flight
Hg	2401	Kerzar, 65	
	2481	Killian, 30	
H_2	42	Bennett, 42	
	188	Bernstein, 62	
	195	Townsend, 21	Magnetic Deflection
	199	Townsend, 22	Magnetic Deflection
	530	Pack, 61	Time of Flight
	627	Breare, 63	Time of Flight
	1155	Lowke, 63	Time of Flight
	1314	Schlumbohm, 65	Time of Flight
	1381	Bradbury, 36	Time of Flight
	1625	Schlumbohm, 65	Time of Flight
	1964	Hurst, 66	Time of Flight
	1971	Haines, 15	Time of Flight
	2133	Wahlin, 26	Time of Flight
	2135	Loeb, 24	Time of Flight
	2137	Loeb, 22	Time of Flight
	2153	Jager, 62	
	2154	Frommhold, 60	Time of Flight

Drift Velocity (Experimental)—*Continued*

	2239	Bennett, 40	
	2278	Bailey, 30	
	2279	Bailey, 30	
	2285	Prasad, 67	Time of Flight
	2289	Hall, 55	Magnetic Deflection
	2399	English, 53	Time of Flight
	2489	Crompton, 57	Time of Flight
	2514	Bennett, 42	
	2594	Harris, 34	
	2952	Bradbury, 32	
	2992	Crompton, 68	Time of Flight
	3264	Craig, 53	
	3313	Wagner, 67	Time of Flight
	3382	Grunberg, 67	Time of Flight
	3384	Creaser, 67	Magnetic Deflection
	3459	Blevin, 67	Time of Flight
	3788	Breare, 64	Time of Flight
	4017	Gill, 49	
	4058	Grunberg, 68	Time of Flight
	4484	Crompton, 70	Time of Flight
	4913	Crompton, 71	Time of Flight
	4916	Robertson, 71	Time of Flight
	5103	Bartels, 72	Time of Flight
	5960	Errett, 51	
p $-H_2$	2267	Crompton, 67	
	3659	Crompton, 68	Time of Flight
	4913	Crompton, 71	Time of Flight
	4916	Robertson, 71	Time of Flight
D_2	42	Bennett, 42	
	188	Bernstein, 62	
	439	Pack, 62	Time of Flight
	1428	Hall, 55	Time of Flight
	2039	McIntosh, 66	Time of Flight
	2992	Crompton, 68	Time of Flight
	3384	Creaser, 67	Magnetic Deflection
	4913	Crompton, 71	Time of Flight
N_2	195	Townsend, 21	Magnetic Deflection
	530	Pack, 61	Time of Flight
	725	Christophorou, 66	Time of Flight
	732	Bortner, 57	Time of Flight
	1155	Lowke, 63	Time of Flight
	1314	Schlumbohm, 65	Time of Flight
	1333	Colli, 52	Time of Flight
	1387	Nielsen, 36	Time of Flight
	1429	Jory, 65	Magnetic Deflection
	1434	Lowke, 62	Time of Flight
	1565	Christophorou, 65	Time of Flight
	1623	Bowe, 60	Time of Flight
	1625	Schlumbohm, 65	Time of Flight
	1716	Tholl, 64	
	1763	Fischer–Treuenfeld, 65	Time of Flight
	1833	Fink, 65	Time of Flight
	1971	Haines, 15	Time of Flight

Drift Velocity (Experimental) — *Continued*

	2046	Phelps, 59	Time of Flight
	2049	Wahlin, 24	Time of Flight
	2055	Klema, 50	Time of Flight
	2090	Loeb, 22	Time of Flight
	2135	Loeb, 24	Time of Flight
	2136	Wagner, 62	Time of Flight
	2154	Frommhold, 60	Time of Flight
	2164	Anderson, 64	
	2261	Nagy, 60	Time of Flight
	2285	Prasad, 67	Time of Flight
	2343	Meisel, 65	
	2504	Loeb, 21	Time of Flight
	2514	Bennett, 42	
	2529	Wagner, 63	Time of Flight
	2559	Christophorou, 65	Time of Flight
	2920	Levine, 64	Time of Flight
	2952	Bradbury, 32	
	3313	Wagner, 67	Time of Flight
	3382	Grunberg, 67	Time of Flight
	3460	Blevin, 67	Time of Flight
	3662	Hendrick, 68	Time of Flight
	4017	Gill, 49	
	4058	Grunberg, 68	Time of Flight
	4971	Wagner, 64	Time of Flight
	5188	Allen, 70	Time of Flight
	5960	Errett, 51	
O_2	195	Townsend, 21	Magnetic Deflection
	727	Doehring, 51	Time of Flight
	1314	Schlumbohm, 65	Time of Flight
	1317	Bradbury, 33	
	1336	Herreng, 52	Time of Flight
	1412	Nielsen, 37	Time of Flight
	1625	Schlumbohm, 65	Time of Flight
	2089	Brose, 25	Magnetic Deflection
	2154	Frommhold, 60	Time of Flight
	2370	Frommhold, 64	Time of Flight
	5135	Nelson, 72	Time of Flight
Cl_2	682	Bailey, 35	
Br_2	683	Bailey, 37	Magnetic Deflection
I_2	677	Healey, 38	Magnetic Deflection
HCl	2088	Bailey, 30	Magnetic Deflection
CO	200	Skinker, 23	Magnetic Deflection
	439	Pack, 62	Time of Flight
	1725	Wahlin, 25	Time of Flight
	3313	Wagner, 67	Time of Flight
NO	200	Skinker, 23	Magnetic Deflection
	2385	Bailey, 34	Magnetic Deflection
	4943	Parkes, 72	Time of Flight

Drift Velocity (Experimental)—*Continued*

H_2O	439	Pack, 62	Time of Flight
	1150	Lowke, 63	Time of Flight
	1964	Hurst, 66	Time of Flight
	2088	Bailey, 30	Magnetic Deflection
	2305	Ryzko, 65	Time of Flight
	5960	Errett, 51	
BF_3	3187	Bistline, 48	Time of Flight
CO_2	198	Skinker, 22	Magnetic Deflection
	439	Pack, 62	Time of Flight
	725	Christophorou, 66	Time of Flight
	732	Bortner, 57	Time of Flight
	1184	Hurst, 63	Time of Flight
	1314	Schlumbohm, 65	Time of Flight
	1625	Schlumbohm, 65	Time of Flight
	1833	Fink, 65	Time of Flight
	2041	Elford, 66	Time of Flight
	2154	Frommhold, 60	Time of Flight
	2399	English, 53	Time of Flight
	2559	Christophorou, 65	Time of Flight
	2920	Levine, 64	Time of Flight
	3313	Wagner, 67	Time of Flight
	4203	Lehning, 68	Time of Flight
	5188	Allen, 70	Time of Flight
	5206	Hurst, 63	Time of Flight
	5960	Errett, 51	
NH_3	439	Pack, 62	Time of Flight
	1412	Nielsen, 37	Time of Flight
	2088	Bailey, 30	Magnetic Deflection
N_2O	159	Bailey, 32	Magnetic Deflection
	200	Skinker, 23	Magnetic Deflection
	439	Pack, 62	Time of Flight
	1412	Nielsen, 37	Time of Flight
SiH_4	1917	Cottrell, 65	Time of Flight
	5638	Pollock, 68	
SiD_4	1917	Cottrell, 65	Time of Flight
	5638	Pollock, 68	
PH_3	5200	Cottrell, 68	Time of Flight
SF_6	5119	Naidu, 72	Time of Flight
	5244	Dutton, 71	
AsH_3	1917	Cottrell, 65	Time of Flight
CH_4	725	Christophorou, 66	Time of Flight
	732	Bortner, 57	Time of Flight
	973	Frommhold, 59	Time of Flight
	1314	Schlumbohm, 65	Time of Flight
	1716	Tholl, 64	

Drift Velocity (Experimental) — *Continued*

	1833	Fink, 65	Time of Flight
	1917	Cottrell, 65	Time of Flight
	1949	Cookson, 66	Time of Flight
	2156	Franke, 60	Time of Flight
	2269	Bowman, 67	Time of Flight
	2399	English, 53	Time of Flight
	2574	Frommhold, 60	Time of Flight
	3313	Wagner, 67	Time of Flight
	5638	Pollock, 68	
C_2H_2	1917	Cottrell, 65	Time of Flight
	2269	Bowman, 67	Time of Flight
	5200	Cottrell, 68	Time of Flight
C_2H_4	203	Bannon, 28	Magnetic Deflection
	488	Christophorou, 66	Time of Flight
	725	Christophorou, 66	Time of Flight
	732	Bortner, 57	Time of Flight
	1184	Hurst, 63	Time of Flight
	1917	Cottrell, 65	Time of Flight
	1964	Hurst, 66	Time of Flight
	2061	Hamilton, 66	Time of Flight
	2269	Bowman, 67	Time of Flight
	2559	Christophorou, 65	Time of Flight
	3313	Wagner, 67	Time of Flight
	3662	Hendrick, 68	Time of Flight
	5200	Cottrell, 68	Time of Flight
	5206	Hurst, 63	Time of Flight
C_2H_6	1917	Cottrell, 65	Time of Flight
	2269	Bowman, 67	Time of Flight
	3475	Huber, 68	Time of Flight
	4022	Huber, 69	
	5200	Cottrell, 68	Time of Flight
C_3H_6	732	Bortner, 57	Time of Flight
	2269	Bowman, 67	Time of Flight
C_3H_8	725	Christophorou, 66	Time of Flight
	1917	Cottrell, 65	Time of Flight
	2559	Christophorou, 65	Time of Flight
	4022	Huber, 69	
	5200	Cottrell, 68	Time of Flight
C_4H_8	2269	Bowman, 67	Time of Flight
C_4H_{10}	725	Christophorou, 66	Time of Flight
	2559	Christophorou, 65	Time of Flight
C_5H_{12}	725	Christophorou, 66	Time of Flight
	2284	McGee, 28	Magnetic Deflection
	2559	Christophorou, 65	Time of Flight
C_6H_6	725	Christophorou, 66	Time of Flight
	1314	Schlumbohm, 65	Time of Flight
	2559	Christophorou, 65	Time of Flight

Drift Velocity (Experimental)—*Continued*

CD_4	1917	Cottrell, 65	Time of Flight
	5638	Pollock, 68	
CH_3Cl	1917	Cottrell, 65	Time of Flight
	5200	Cottrell, 68	Time of Flight
CH_3OH	5200	Cottrell, 68	Time of Flight
C_2D_2	1917	Cottrell, 65	Time of Flight
$C_2H_{62}O$	1917	Cottrell, 65	Time of Flight
C_2H_5Cl	487	Christophorou, 66	Time of Flight
C_2H_5OH	1917	Cottrell, 65	Time of Flight
$(C_2H_5)_2O$	1314	Schlumbohm, 65	Time of Flight
	2154	Frommhold, 60	Time of Flight
o $-C_6H_4Cl_2$	487	Christophorou, 66	Time of Flight
m $-C_6H_4Cl_2$	487	Christophorou, 66	Time of Flight
p $-C_6H_4Cl_2$	487	Christophorou, 66	Time of Flight
C_6H_5Cl	487	Christophorou, 66	Time of Flight
C_6H_5Br	487	Christophorou, 66	Time of Flight
C_6D_5Br	487	Christophorou, 66	Time of Flight
CF_4	5051	Naidu, 72	Time of Flight
CCl_2F_2	5183	Naidu, 69	Time of Flight
C_2F_6	5051	Naidu, 72	Time of Flight
C_3F_8	5051	Naidu, 72	Time of Flight
	5123	Prasad, 70	Time of Flight
C_4F_{10}	5051	Naidu, 72	Time of Flight
Organic	487	Christophorou, 66	Time of Flight
	1314	Schlumbohm, 65	Time of Flight
	1565	Christophorou, 65	Time of Flight
	1917	Cottrell, 65	Time of Flight
	5052	Naidu, 72	Time of Flight
Air	1317	Bradbury, 33	
	1412	Nielsen, 37	Time of Flight
	2054	Huxley, 49	Magnetic Deflection
	2104	Townsend, 13	Magnetic Deflection
	2263	Loeb, 23	Time of Flight
	2305	Ryzko, 65	Time of Flight

Drift Velocity (Experimental)—*Continued*

	2370	Frommhold, 64	Time of Flight
	2594	Harris, 34	
	2820	Deb, 56	
	3165	Hessenauer, 67	Time of Flight
Mixture	42	Bennett, 42	
	199	Townsend, 22	Magnetic Deflection
	488	Christophorou, 66	Time of Flight
	682	Bailey, 35	
	725	Christophorou, 66	Time of Flight
	732	Bortner, 57	Time of Flight
	1016	Hurst, 61	Time of Flight
	1150	Lowke, 63	Time of Flight
	1155	Lowke, 63	Time of Flight
	1333	Colli, 52	Time of Flight
	1379	Hurst, 63	Time of Flight
	1467	Nolan, 65	Time of Flight
	1716	Tholl, 64	
	2042	Kirshner, 52	Time of Flight
	2055	Klema, 50	Time of Flight
	2061	Hamilton, 66	Time of Flight
	2141	Bortner, 58	Time of Flight
	2151	Stevenson, 52	Time of Flight
	2155	Dibbern, 61	Time of Flight
	2261	Nagy, 60	Time of Flight
	2280	Bailey, 24	Magnetic Deflection
	2305	Ryzko, 65	Time of Flight
	2399	English, 53	Time of Flight
	2459	Fischer, 66	
	2514	Bennett, 42	
	2532	Compton, 66	Time of Flight
	2559	Christophorou, 65	Time of Flight
	2581	Blair, 62	Time of Flight
	2582	Dibbern, 62	Time of Flight
	2821	Colli, 51	
	2883	Townsend, 22	Magnetic Deflection
	2920	Levine, 64	Time of Flight
	2987	Colli, 53	Time of Flight
	3165	Hessenauer, 67	Time of Flight
	3550	Den Hartog, 49	Time of Flight
	3551	Den Hartog, 47	Time of Flight
	4018	Riemann, 44	
	4022	Huber, 69	
	4901	Fleming, 72	Time of Flight
	5960	Errett, 51	

Drift Velocity (Theoretical)

	2187	Huxley, 51
	2198	Sodha, 59
	2201	Compton, 23
	2256	Huxley, 60
	2338	Huxley, 37
	2339	Gvosdover, 37
	2765	Bailey, 37
	2806	Pearson, 63
	2877	Ritchie, 67
	3275	Dallenbach, 66
	3467	Cavalleri, 68
	3592	Lucas, 67
	3655	Hassan, 68
	3711	Wilhelm, 67
	3720	Hertz, 24
He	273	Allen, 37
	397	Barbiere, 51

Drift Velocity (Theoretical)—*Continued*

	1062	Frost, 64
	1440	Heylen, 63
	2202	Compton, 23
	2812	Llewellyn–Jones, 44
	3463	Bell, 68
	3714	Elkomoss, 68
	3897	Itoh, 60
	4053	Pfau, 69
	4057	Bortnik, 65
	4909	Hughes, 70
	5490	Englert, 71
Ne	273	Allen, 37
	1440	Heylen, 63
	1745	Salmon, 63
	2351	Druyvesteyn, 37
	4053	Pfau, 69
	4909	Hughes, 70
Ar	273	Allen, 37
	292	Engelhardt, 64
	397	Barbiere, 51
	881	Golant, 59
	1062	Frost, 64
	1440	Heylen, 63
	2202	Compton, 23
	2397	Uman, 60
	4053	Pfau, 69
	5126	Sakai, 72
Kr	1062	Frost, 64
	4053	Pfau, 69
Xe	1062	Frost, 64
	4053	Pfau, 69
Cs	3305	Postma, 68
H_2	181	Frost, 62
	260	Engelhardt, 63
	1043	Frost, 62
	1636	Heylen, 60
	1638	Heylen, 60
	1783	Heylen, 65
	1950	Heylen, 66
	2202	Compton, 23
	2352	Kihara, 52
	4450	Gibson, 70
	3463	Bell, 68
D_2	260	Engelhardt, 63
	4450	Gibson, 70
N_2	181	Frost, 62
	218	Engelhardt, 64
	1043	Frost, 62
	1447	Heylen, 62
	1950	Heylen, 66
	2202	Compton, 23
	3463	Bell, 68
O_2	1447	Heylen, 62
	1950	Heylen, 66
	2202	Compton, 23
	2553	Hake, 67
CO	1446	Wahlin, 30
	2553	Hake, 67
CO_2	2202	Compton, 23
	2553	Hake, 67
SiH_4	5638	Pollock, 68
SiD_4	5638	Pollock, 68
CH_4	5638	Pollock, 68
C_2H_2	2142	Heylen, 62
C_2H_4	2142	Heylen, 62
C_2H_6	1950	Heylen, 66
	2142	Heylen, 62
CD_4	5638	Pollock, 68
Air	1447	Heylen, 62
	1950	Heylen, 66
Mixture	292	Engelhardt, 64
	2397	Uman, 60
	2921	Uman, 61
	4909	Hughes, 70

(Diffusion Coefficient)/Mobility (Experimental)

He	201	Townsend, 23
	1036	Warren, 62
	1489	Crompton, 65
	2433	Crompton, 67
Ar	197	Townsend, 22
	199	Townsend, 22
	1036	Warren, 62

(Diffusion Coefficient)/Mobility (Experimental)—*Continued*

H_2	195	Townsend, 21
	199	Townsend, 22
	352	Crompton, 52
	689	Crompton, 63
	736	Cochran, 62
	841	Varnerin, 50
	1036	Warren, 62
	1264	Lawson, 65
	1437	Crompton, 66
	1438	Crompton, 62
	1622	Crompton, 65
	1625	Schlumbohm, 65
	1778	Lawson, 65
	2110	Huxley, 55
	2992	Crompton, 68
	3303	Naidu, 68
	5050	Virr, 72
	5230	Virr, 70
	5234	Kontoleon, 71
$p-H_2$	2267	Crompton, 67
	3659	Crompton, 68
D_2	1036	Warren, 62
	1428	Hall, 55
	2039	McIntosh, 66
	2992	Crompton, 68
N_2	195	Townsend, 21
	352	Crompton, 52
	689	Crompton, 63
	736	Cochran, 62
	1036	Warren, 62
	1429	Jory, 65
	1625	Schlumbohm, 65
	3303	Naidu, 68
	5230	Virr, 70
O_2	195	Townsend, 21
	649	Huxley, 59
	1269	Rees, 65
	1625	Schlumbohm, 65
	2089	Brose, 25
	5226	Naidu, 70
Cl_2	682	Bailey, 35
Br_2	683	Bailey, 37
I_2	677	Healey, 38
HCl	2088	Bailey, 30
	2567	Bailey, 29
CO	200	Skinker, 23
	1036	Warren, 62
NO	200	Skinker, 23
	2385	Bailey, 34
H_2O	1618	Crompton, 65
	2088	Bailey, 30
	2463	Crompton, 66
CO_2	198	Skinker, 22
	736	Cochran, 62
	1036	Warren, 62
	1625	Schlumbohm, 65
	2140	Rees, 64
	5230	Virr, 70
NH_3	2088	Bailey, 30
	2567	Bailey, 29
N_2O	159	Bailey, 32
	200	Skinker, 23
SiH_4	1917	Cottrell, 65
	2990	Cottrell, 67
	5638	Pollock, 68
SiD_4	1917	Cottrell, 65
	2990	Cottrell, 67
	5638	Pollock, 68
SF_6	5119	Naidu, 72
CH_4	736	Cochran, 62
	1326	Schlumbohm, 65
	1917	Cottrell, 65
	2990	Cottrell, 67
	3715	Brose, 35
	5638	Pollock, 68
C_2H_2	1917	Cottrell, 65
C_2H_4	203	Bannon, 28
	736	Cochran, 62
C_2H_6	1917	Cottrell, 65
	2990	Cottrell, 67
C_3H_6	736	Cochran, 62
C_3H_8	2990	Cottrell, 67
C_5H_{12}	2284	McGee, 28
C_6H_6	1625	Schlumbohm, 65

(Diffusion Coefficient)/Mobility (Experimental) — *Continued*

CD_4	2990	Cottrell, 67
	5638	Pollock, 68
C_2D_2	1917	Cottrell, 65
C_2H_6O	1625	Schlumbohm, 65
	1917	Cottrell, 65
	2990	Cottrell, 67
CF_4	5051	Naidu, 72
CCl_2F_2	5183	Naidu, 69
C_2F_6	5051	Naidu, 72
C_3F_8	5051	Naidu, 72
	5123	Prasad, 70
C_4F_{10}	5051	Naidu, 72
Organic	1625	Schlumbohm, 65
	1917	Cottrell, 65
	5052	Naidu, 72
Air	1332	Bailey, 25
	2054	Huxley, 49
	2097	Crompton, 53
	2104	Townsend, 13
	2813	Rees, 64
	5247	Rao, 71
Mixture	199	Townsend, 22
	677	Healey, 38
	682	Bailey, 35
	683	Bailey, 37
	2280	Bailey, 24
	4901	Fleming, 72

(Diffusion Coefficient)/Mobility (Theoretical)

	2766	Townsend, 37
	3484	Liley, 67
He	273	Allen, 37
	1062	Frost, 64
	2250	Orient, 66
	4052	Lowke, 69
	4053	Pfau, 69
	4909	Hughes, 70
Ne	273	Allen, 37
	2250	Orient, 66
	4053	Pfau, 69
	4909	Hughes, 70
Ar	273	Allen, 37
	292	Engelhardt, 64
	1062	Frost, 64
	4052	Lowke, 69
	4053	Pfau, 69
Kr	1062	Frost, 64
	4052	Lowke, 69
	4053	Pfau, 69
Xe	1062	Frost, 64
	4052	Lowke, 69
	4053	Pfau, 69
H_2	181	Frost, 62
	260	Engelhardt, 63
	1043	Frost, 62
	4052	Lowke, 69
	4450	Gibson, 70
D_2	260	Engelhardt, 63
	4052	Lowke, 69
	4450	Gibson, 70
N_2	181	Frost, 62
	218	Engelhardt, 64
	1043	Frost, 62
	4052	Lowke, 69
	5233	Kline, 71
O_2	2553	Hake, 67
	4052	Lowke, 69
CO	2553	Hake, 67
	4052	Lowke, 69
H_2O	4052	Lowke, 69
CO_2	2553	Hake, 67
	4052	Lowke, 69
SiH_4	5638	Pollock, 68
SiD_4	5638	Pollock, 68
CH_4	5638	Pollock, 68
CD_4	5638	Pollock, 68
Mixture	292	Engelhardt, 64
	4909	Hughes, 70

Diffusion Coefficient (Experimental)

He	3313	Wagner, 67	Longitudinal
	4048	Nelson, 69	
	4049	Cavalleri, 69	
Ne	1126	Cavalleri, 64	
	4048	Nelson, 69	
	4050	Cavalleri, 65	
Ar	3313	Wagner, 67	Longitudinal
	4048	Nelson, 69	
H_2	188	Bernstein, 62	
	1964	Hurst, 66	Longitudinal
	2295	Madan, 57	
	3313	Wagner, 67	Longitudinal
	3788	Breare, 64	Longitudinal
	4048	Nelson, 69	
D_2	188	Bernstein, 62	
N_2	1833	Fink, 65	Longitudinal
	3313	Wagner, 67	Longitudinal
	4048	Nelson, 69	
O_2	5135	Nelson, 72	
CO	3313	Wagner, 67	Longitudinal
	4048	Nelson, 69	
H_2O	1964	Hurst, 66	Longitudinal
CO_2	1184	Hurst, 63	Longitudinal
	1833	Fink, 65	Longitudinal
	3313	Wagner, 67	Longitudinal
	4048	Nelson, 69	
	5206	Hurst, 63	Longitudinal
CH_4	973	Frommhold, 59	Longitudinal
	1833	Fink, 65	Longitudinal
	2574	Frommhold, 60	Longitudinal
	3313	Wagner, 67	Longitudinal
	4048	Nelson, 69	
C_2H_4	1184	Hurst, 63	Longitudinal
	1964	Hurst, 66	Longitudinal
	3313	Wagner, 67	Longitudinal
	4048	Nelson, 69	
	5206	Hurst, 63	Longitudinal

Diffusion Coefficient (Theoretical)

Gas	Ref.	Author
	2198	Sodha, 59
	2256	Huxley, 60
	2437	Shkarofsky, 61
	2877	Ritchie, 67
	3592	Lucas, 67
	3711	Wilhelm, 67
	3719	Townsend, 38
	3785	Van Leeuwen, 67
	3796	Devoto, 66
	3800	Golant, 61
	4194	Weijland, 68
He	1440	Heylen, 63
	3463	Bell, 68
	4053	Pfau, 69
	5490	Englert, 71
Ne	1440	Heylen, 63
	4053	Pfau, 69
	4063	Lloyd, 60
Ar	1440	Heylen, 63
	2438	Tan, 65
	3798	Devoto, 67
	4053	Pfau, 69
Kr	4053	Pfau, 69
Xe	4053	Pfau, 69
H_2	3463	Bell, 68
N_2	3463	Bell, 68
C_2H_2	2142	Heylen, 62
C_2H_4	2142	Heylen, 62
C_2H_6	2142	Heylen, 62

Attachment Coefficient (Experimental)

Gas	Ref.	Author	Method
Br	4086	Razzak, 69	Drift Tube, Spatial
H_2	1240	Whitmer, 56	Plasma Decay
	5500	Cronin, 70	Plasma Decay
O_2	131	Chanin, 59	Drift Tube, Temporal
	573	Dutton, 63	Drift Tube, Spatial
	649	Huxley, 59	Drift Tube, Spatial
	711	Sexton, 60	Plasma Decay
	727	Doehring, 51	Drift Tube, Temporal
	762	Brodskii, 66	Plasma Decay
	791	Harrison, 53	Drift Tube, Spatial
	861	Prasad, 61	Drift Tube, Spatial
	961	Freely, 64	Drift Tube, Spatial
	1006	Chatterton, 61	Drift Tube, Spatial
	1269	Rees, 65	Drift Tube, Spatial
	1315	Geballe, 52	Drift Tube, Spatial
	1317	Bradbury, 33	Drift Tube, Spatial
	1322	Burch, 57	Drift Tube, Temporal
	1336	Herreng, 52	Drift Tube, Temporal
	1383	Chanin, 62	Drift Tube, Temporal
	1433	Kuffel, 59	Drift Tube, Temporal
	1444	Frommhold, 64	Drift Tube, Temporal
	1445	Schlumbohm, 59	Drift Tube, Temporal
	1565	Christophorou, 65	Drift Tube, Temporal
	1601	Anisimov, 64	Plasma Decay
	1633	Hackam, 65	Plasma Decay
	1662	Pack, 66	Drift Tube, Temporal
	1724	Schlumbohm. 62	Drift Tube, Temporal
	2093	Cravath, 29	Drift Tube, Spatial
	2370	Frommhold, 64	Drift Tube, Temporal
	2387	Schlumbohm, 60	Drift Tube, Temporal

Attachment Coefficient (Experimental)—*Continued*

	2461	Taylor, 66	Plasma Decay
	2462	Prasad, 66	Drift Tube, Spatial
	2492	De Bitetto, 58	Drift Tube, Spatial
	2555	Sukhum, 67	Drift Tube, Spatial
	2572	Dubs, 60	
	3154	Phelps, 61	Drift Tube, Temporal
	3495	Margenau, 46	Plasma Decay
	3647	Stein, 68	Plasma Decay
	4043	Thomas–Betts, 69	Drift Tube, Spatial
	4095	Biondi, 51	Plasma Decay
	4096	Holt, 59	Plasma Decay
	4919	Grunberg, 69	Drift Tube, Temporal
	5047	Spence, 72	
	5125	Warman, 71	Plasma Decay
	5131	Truby, 72	Plasma Decay
	5226	Naidu, 70	
	5227	Kinsman, 70	
	5770	Hirsh, 69	Plasma Decay
Cl_2	682	Bailey, 35	Drift Tube, Spatial
	2099	Bradbury, 34	Drift Tube, Spatial
	2158	Wahlin, 22	
	2224	Bozin, 67	Drift Tube, Spatial
Br_2	683	Bailey, 37	Drift Tube, Spatial
I_2	541	Biondi, 58	Plasma Decay
	677	Healey, 38	Drift Tube, Spatial
	4108	Truby, 69	Plasma Decay
HCl	2088	Bailey, 30	Drift Tube, Spatial
	2099	Bradbury, 34	Drift Tube, Spatial
	2567	Bailey, 29	Drift Tube, Spatial
	3007	Christophorou, 68	Drift Tube, Temporal
HBr	3007	Christophorou, 68	Drift Tube, Temporal
HI	3007	Christophorou, 68	Drift Tube, Temporal
DCl	3007	Christophorou, 68	Drift Tube, Temporal
DBr	3007	Christophorou, 68	Drift Tube, Temporal
DI	3007	Christophorou, 68	Drift Tube, Temporal
CO	1254	Bhalla, 61	Drift Tube, Spatial
	2099	Bradbury, 34	Drift Tube, Spatial
	2158	Wahlin, 22	
	2408	Chatterton, 65	Drift Tube, Spatial
	4016	Davies, 69	Drift Tube, Spatial
	5243	Parr, 71	Drift Tube, Spatial
NO	658	Gunton, 63	Plasma Decay
	1181	Gunton, 61	Plasma Decay
	1608	Gunton, 65	Plasma Decay

Attachment Coefficient (Experimental)—*Continued*

	2099	Bradbury, 34	Drift Tube, Spatial
	2455	Biondi, 66	Plasma Decay
	3229	Mentzoni, 67	Plasma Decay
	3610	Weller, 68	Plasma Decay
H_2O	1433	Kuffel, 59	Drift Tube, Temporal
	1618	Crompton, 65	Drift Tube, Spatial
	1911	Ryzko, 66	Drift Tube, Temporal
	2088	Bailey, 30	Drift Tube, Spatial
	2093	Cravath, 29	Drift Tube, Spatial
	2100	Bradbury, 34	Drift Tube, Spatial
	2294	Prasad, 60	Drift Tube, Spatial
	2463	Crompton, 66	Drift Tube, Spatial
	5248	Parr, 72	Drift Tube, Temporal
H_2S	2100	Bradbury, 34	Drift Tube, Spatial
CO_2	948	Bhalla, 60	Drift Tube, Spatial
	1724	Schlumbohm, 62	Drift Tube, Temporal
	2408	Chatterton, 65	Drift Tube, Spatial
	3435	Conti, 67	Drift Tube, Spatial
	4843	Baker, 70	Drift Tube, Spatial
	5290	Bouby, 71	Drift Tube, Spatial
NH_3	2088	Bailey, 30	Drift Tube, Spatial
	2099	Bradbury, 34	Drift Tube, Spatial
	2158	Wahlin, 22	
	2273	Bailey, 28	Drift Tube, Spatial
	2567	Bailey, 29	Drift Tube, Spatial
	5248	Parr, 72	Drift Tube, Temporal
NO_2	1649	Hasted, 65	Plasma Decay
N_2O	159	Bailey, 32	Drift Tube, Spatial
	2100	Bradbury, 34	Drift Tube, Spatial
	3680	Phelps, 68	Drift Tube, Temporal
SO_2	1724	Schlumbohm, 62	Drift Tube, Temporal
	2100	Bradbury, 34	Drift Tube, Spatial
	5290	Bouby, 71	Drift Tube, Spatial
SF_6	788	McAfee, 63	Drift Tube, Temporal
	1198	Compton, 66	Drift Tube, Temporal
	1260	Bhalla, 62	Drift Tube, Spatial
	1274	McAfee, 55	Drift Tube, Temporal
	1649	Hasted, 65	Plasma Decay
	1724	Schlumbohm, 62	Drift Tube, Temporal
	1923	Mahan, 66	Plasma Decay
	2544	Edelson, 64	Drift Tube, Temporal
	3662	Hendrick, 68	Drift Tube, Temporal
	4195	Chen, 68	
	5053	Boyd, 71	Drift Tube, Spatial
C_2H_2	2158	Wahlin, 22	

Attachment Coefficient (Experimental)—*Continued*

C_2H_4	2158	Wahlin, 22	
	5290	Bouby, 71	Drift Tube, Spatial
C_2H_6	2158	Wahlin, 22	
C_5H_{12}	2284	McGee, 28	Drift Tube, Spatial
$C_{10}H_8$	4099	Chaney, 70	Drift Tube, Temporal
$CHCl_3$	4190	Blaunstein, 68	Drift Tube, Temporal
CH_2Cl_2	4190	Blaunstein, 68	Drift Tube, Temporal
CH_3Br	3600	Razzak, 68	Drift Tube, Spatial
C_2H_5Cl	2158	Wahlin, 22	
	487	Christophorou, 66	Drift Tube, Temporal
C_2HCl_3	4190	Blaunstein, 68	Drift Tube, Temporal
$C_2H_3Cl_3$	4190	Blaunstein, 68	Drift Tube, Temporal
o $-C_6H_4Cl_2$	487	Christophorou, 66	Drift Tube, Temporal
m $-C_6H_4Cl_2$	487	Christophorou, 66	Drift Tube, Temporal
p $-C_6H_4Cl_2$	487	Christophorou, 66	Drift Tube, Temporal
C_6H_5Cl	487	Christophorou, 66	Drift Tube, Temporal
C_6H_5Br	487	Christophorou, 66	Drift Tube, Temporal
C_6D_5Br	487	Christophorou, 66	Drift Tube, Temporal
$C_6H_5NO_2$	1198	Compton, 66	Drift Tube, Temporal
CF_4	3465	Bozin, 68	Drift Tube, Spatial
	5051	Naidu, 72	
CCl_4	4190	Blaunstein, 68	Drift Tube, Temporal
CCl_2F_2	791	Harrison, 53	Drift Tube, Spatial
	1724	Schlumbohm, 62	Drift Tube, Temporal
	2345	Moruzzi, 63	Drift Tube, Spatial
	2449	Moruzzi, 63	Drift Tube, Spatial
	5229	Boyd, 70	Drift Tube, Spatial
CF_3SF_5	791	Harrison, 53	Drift Tube, Spatial
C_2F_6	3465	Bozin, 68	Drift Tube, Spatial
	5051	Naidu, 72	
C_3F_8	2302	Moruzzi, 63	Drift Tube, Spatial
	5051	Naidu, 72	
	5123	Prasad, 70	

Attachment Coefficient (Experimental) — *Continued*

C_4F_{10}	3604	Razzak, 68	
	5051	Naidu, 72	
C_7F_{14}	1923	Mahan, 66	Plasma Decay
	4195	Chen, 68	
Organic	487	Christophorou, 66	Drift Tube, Temporal
	1565	Christophorou, 65	Drift Tube, Temporal
	3712	Blaunstein, 68	Drift Tube, Temporal
	4185	Christophorou, 69	Drift Tube, Temporal
	4187	Wentworth, 66	
	5052	Naidu, 72	
Air	762	Brodskii, 66	Plasma Decay
	791	Harrison, 53	Drift Tube, Spatial
	1317	Bradbury, 33	Drift Tube, Spatial
	1332	Bailey, 25	Drift Tube, Spatial
	1433	Kuffel, 59	Drift Tube, Temporal
	1444	Frommhold, 64	Drift Tube, Temporal
	1911	Ryzko, 66	Drift Tube, Temporal
	2047	Prasad, 59	Drift Tube, Spatial
	2149	Kuffel, 58	Drift Tube, Spatial
	2235	Ryzko, 67	Drift Tube, Temporal
	2370	Frommhold, 64	Drift Tube, Temporal
	2388	Dutton, 60	Drift Tube, Spatial
	2407	Dutton, 63	Drift Tube, Spatial
	2408	Chatterton, 65	Drift Tube, Spatial
	2488	Dutton, 63	Drift Tube, Spatial
	2528	Dutton, 63	Drift Tube, Spatial
	2953	Bailey, 32	Drift Tube, Spatial
	3165	Hessenauer, 67	Drift Tube, Temporal
Mixture	682	Bailey, 35	Drift Tube, Spatial
	738	Pack, 66	Drift Tube, Temporal
	956	Stockdale, 64	Drift Tube, Temporal
	961	Freely, 64	Drift Tube, Spatial
	1016	Hurst, 61	Drift Tube, Temporal
	1267	Hurst, 59	Drift Tube, Temporal
	1317	Bradbury, 33	Drift Tube, Spatial
	1379	Hurst, 63	
	1433	Kuffel, 59	Drift Tube, Temporal
	1633	Hackam, 65	Plasma Decay
	1649	Hasted, 65	Plasma Decay
	1923	Mahan, 66	Plasma Decay
	2093	Cravath, 29	Drift Tube, Spatial
	2099	Bradbury, 34	Drift Tube, Spatial
	2100	Bradbury, 34	Drift Tube, Spatial
	2141	Bortner, 58	Drift Tube, Temporal
	2294	Prasad, 60	Drift Tube, Spatial
	2407	Dutton, 63	Drift Tube, Spatial
	2408	Chatterton, 65	Drift Tube, Spatial
	2467	Ryzko, 66	Drift Tube, Temporal
	2532	Compton, 66	Drift Tube, Temporal
	2995	Stockdale, 67	Drift Tube, Temporal
	3165	Hessenauer, 67	Drift Tube, Temporal
	3229	Mentzoni, 67	Plasma Decay

Attachment Coefficient (Experimental)—*Continued*

3495	Margenau, 46	Plasma Decay
3595	Mahan, 67	Plasma Decay
3607	Truby, 68	Plasma Decay
3901	Lee, 63	Drift Tube, Temporal
4054	Christophorou, 70	Drift Tube, Temporal
4097	Lennon, 61	Plasma Decay
4192	Bouby, 65	Drift Tube, Spatial
4311	Ghosh, 67	Plasma Decay
5046	McCorkle, 72	Drift Tube, Temporal
5236	Davis, 69	
5237	Davis, 70	
5238	Christophorou, 69	
5770	Hirsh, 69	Plasma Decay

Attachment Coefficient (Theoretical)

H	1603	Dalgarno, 63
	2553	Hake, 67
	4947	Wagner, 71
I_2	4047	Shipsey, 70
O	1180	Massey, 43
O_2	337	Tozer, 58
	1285	Bloch, 35
	2086	Penning, 38
CO_2	2553	Hake, 67
Air	337	Tozer, 58
	4947	Wagner, 71
Mixture	2452	Golant, 57

Detachment Coefficient (Experimental)

O_2	1444	Frommhold, 64	Drift Tube, Temporal
	1633	Hackam, 65	Plasma Decay
	1662	Pack, 66	Drift Tube, Temporal
	2370	Frommhold, 64	Drift Tube, Temporal
	2462	Prasad, 66	Drift Tube, Spatial
	2555	Sukhum, 67	Drift Tube, Spatial
	2994	Eccles, 67	Drift Tube, Spatial
	3154	Phelps, 61	Drift Tube, Temporal
	4920	Eccles, 70	Drift Tube, Spatial
	4949	Brabanec, 72	Drift Tube, Spatial
SF_6	3472	Eccles, 67	Drift Tube, Spatial
Organic	4185	Christophorou, 69	Drift Tube, Temporal
Air	1444	Frommhold, 64	Drift Tube, Temporal
	2235	Ryzko, 67	Drift Tube, Temporal
	2370	Frommhold, 64	Drift Tube, Temporal
Mixture	1633	Hackam, 65	Plasma Decay
	3042	Fehsenfeld, 66	
	3352	Moruzzi, 68	Drift Tube, Temporal
	4311	Ghosh, 67	Plasma Decay
	4312	Malliaris, 68	
	4313	Johnston, 68	
	5700	Moruzzi, 66	

Detachment Coefficient (Theoretical)

H	3652	Dalgarno, 67		4948	Prasad, 65
O_2	4947	Wagner, 71	Air	4947	Wagner, 71

Excitation Coefficient (Experimental)

C^{+4}	3656	Kunze, 68	Radiation
He	336	Corrigan, 58	
H_2	354	Corrigan, 58	Radiation
	921	Legler, 63	Radiation
	1761	Nygaard, 65	Radiation
	2229	Nygaard, 63	Radiation
	2502	Lunt, 37	Radiation
	3111	Von Engel, 56	Radiation
	3240	Geballe, 44	Radiation
	3722	Nygaard, 65	Radiation
	4950	Pool, 37	
	4951	Shaw, 59	
N_2	921	Legler, 63	Radiation
	4993	Teich, 72	
O_2	3267	Teich, 67	
	3268	Teich, 67	
CO_2	3267	Teich, 67	
	4993	Teich, 72	
	5607	Wiegand, 70	
	5702	Kutszegi, 69	
SF_6	4993	Teich, 72	
Air	3267	Teich, 67	
Mixture	3267	Teich, 67	

Excitation Coefficient (Theoretical)

He	3897	Itoh, 60	Hg	3270	Cayless, 59
	4057	Bortnik, 65			
	4909	Hughes, 70	H_2	260	Engelhardt, 63
	5701	Phelps, 59		2109	Lunt, 36
Ne	2501	Glotov, 38	D_2	260	Engelhardt, 63
	3431	Kagan, 63			
	4909	Hughes, 70	N_2	218	Engelhardt, 64
Ar	3432	Kagan, 63	Mixture	2501	Glotov, 38
				4909	Hughes, 70

Ionization Coefficient (Experimental)

He	619	Townsend, 34	Townsend
	646	Chanin, 64	Townsend
	900	Davies, 63	Townsend
	1160	Fletcher, 63	Townsend
	1173	Davies, 62	Townsend
	1250	Dutton, 63	Townsend
	2286	Dutton, 67	Townsend
	2406	Dutton, 65	Townsend
	2435	Burkley, 67	
	2496	Townsend, 31	
	2810	Townsend, 24	Townsend
	2816	Gill, 08	Townsend
	3171	Gill, 12	Townsend
	3272	Townsend, 28	
	4049	Cavalleri, 69	
	4910	Dutton, 71	Townsend
	5077	Dutton, 72	Townsend
	5771	Jones, 69	
C^{+4}	3656	Kunze, 68	
Ne	621	Davies, 60	Townsend
	730	Townsend, 28	Townsend
	751	Chanin, 63	Townsend
	1160	Fletcher, 63	Townsend
	2138	Davies, 59	Townsend
	2237	Kruithof, 40	Townsend
	2341	Glotov, 37	Townsend
	2355	Kruithof, 37	Townsend
	2403	Townsend, 28	Townsend
	2496	Townsend, 31	
	2535	De Hoog, 67	
	3272	Townsend, 28	
	3436	De Hoog, 67	
	3612	Willis, 68	Townsend
	3751	Dutton, 69	Townsend
	5049	Buursen, 72	
Ar	621	Davies, 60	Townsend
	624	Ayres, 23	Townsend
	2108	Engstrom, 40	
	2138	Davies, 59	Townsend
	2139	Kruithof, 36	Townsend
	2237	Kruithof, 40	Townsend
	2333	Golden, 61	Townsend
	2346	Huxford, 39	
	2355	Kruithof, 37	Townsend
	2435	Burkley, 67	
	2587	Golden, 62	Townsend
	2816	Gill, 08	Townsend
	3477	Heylen, 68	Townsend
	3478	Heylen, 68	Townsend
	3908	Scharfman, 64	A C Breakdown
	3956	Yamane, 60	

Ionization Coefficient (Experimental)—*Continued*

	5241	Willis, 71	Townsend
	5295	Carmichael, 72	
Br	4086	Razzak, 69	Townsend
Kr	2237	Kruithof, 40	Townsend
	5293	Heylen, 71	Townsend
Xe	2237	Kruithof, 40	Townsend
	2435	Burkley, 67	
Cs	5202	Davies, 70	Townsend
Hg	898	Smith, 63	Townsend
	1249	Davies, 62	Townsend
	1398	Davies, 65	Townsend
	2368	Grigorovici, 39	
	2481	Killian, 30	
	2930	Badareu, 44	Townsend
	3304	Overton, 68	Townsend
H_2	354	Corrigan, 58	Townsend
	621	Davies, 60	Townsend
	624	Ayres, 23	Townsend
	751	Chanin, 63	Townsend
	779	Wilkes, 55	Townsend
	780	Rose, 56	Townsend
	782	Crompton, 56	Townsend
	784	Crompton, 55	Townsend
	790	Blevin, 57	Townsend
	841	Varnerin, 50	A C Breakdown
	1145	De Bitetto, 56	Townsend
	1160	Fletcher, 63	Townsend
	1174	Barna, 64	Townsend
	1249	Davies, 62	Townsend
	1356	Rose, 56	Townsend
	1640	Hopwood, 56	Townsend
	1712	Prowse, 64	A C Breakdown
	2040	Haydon, 66	Townsend
	2138	Davies, 59	Townsend
	2145	Golden, 65	Townsend
	2148	Haydon, 61	Townsend
	2150	Jones, 58	Townsend
	2154	Frommhold, 60	Pulse Analysis
	2247	Hale, 39	Townsend
	2248	Hale, 39	Townsend
	2271	Townsend, 02	Townsend
	2281	Townsend, 04	Townsend
	2295	Madan, 57	
	2367	Costa, 39	Townsend
	2474	Irish, 64	
	2483	Davies, 58	Townsend
	2561	Cottingham, 63	
	2569	Townsend, 03	Townsend
	2578	Davies, 60	Townsend

Ionization Coefficient (Experimental)—*Continued*

	2593	Townsend, 01	Townsend
	3490	Bishop, 11	Townsend
	4046	Tagashira, 69	Townsend
	4907	Folkard, 71	Townsend
	5105	Blasberg, 71	
	5225	Shallal, 71	Townsend
D_2	1174	Barna, 64	Townsend
	1186	Rork, 64	Townsend
	1249	Davies, 62	Townsend
	1356	Rose, 56	Townsend
	2533	Cottingham, 63	
	2817	Morgan, 67	Townsend
T_2	2465	Edelson, 66	Townsend
N_2	624	Ayres, 23	Townsend
	710	Heylen, 59	Townsend
	789	Posin, 36	Townsend
	1145	De Bitetto, 56	Townsend
	1728	Allen, 63	Townsend
	1741	Ward, 65	Townsend
	1836	Cookson, 66	Townsend
	1836	Cookson, 66	Pulse Analysis
	1948	Blair, 66	Townsend
	2102	Harrison, 57	Townsend
	2154	Frommhold, 60	Pulse Analysis
	2144	Dutton, 52	Townsend
	2275	Bowls, 38	Townsend
	2277	Masch, 32	Townsend
	2448	Bagnall, 65	Townsend
	2556	Masch, 32	Townsend
	2815	Hurst, 06	Townsend
	3908	Scharfman, 64	A C Breakdown
	3297	Jones, 68	Townsend
	4046	Tagashira, 69	Townsend
	4085	Daniel, 69	Townsend
	5102	Haydon, 72	Townsend
	5187	Daniel, 70	Townsend
	5228	McArthur, 70	Pulse Analysis
	5334	Folkard, 73	Townsend
O_2	573	Dutton, 63	Townsend
	791	Harrison, 53	Townsend
	861	Prasad, 61	Townsend
	961	Freely, 64	Townsend
	1315	Geballe, 52	Townsend
	1445	Schlumbohm, 59	Pulse Analysis
	1625	Schlumbohm, 65	Pulse Analysis
	1724	Schlumbohm, 62	Pulse Analysis
	2053	Frommhold, 58	Pulse Analysis
	2154	Frommhold, 60	Pulse Analysis
	2277	Masch, 32	Townsend
	2370	Frommhold, 64	Pulse Analysis
	2387	Schlumbohm, 60	Pulse Analysis

Ionization Coefficient (Experimental)—*Continued*

	2462	Prasad, 66	Townsend
	2492	De Bitetto, 58	Townsend
	2534	Skinner, 63	
	2555	Sukhum, 67	Townsend
	2556	Masch, 32	Townsend
	2908	Dutton, 67	Townsend
	3908	Scharfman, 64	A C Breakdown
	4043	Thomas–Betts, 69	Townsend
	4994	Price, 72	Townsend
	5226	Naidu, 70	
	5227	Kinsman, 70	
Cl_2	2224	Bozin, 67	Townsend
HCl	2562	Townsend, 03	Townsend
CO	1254	Bhalla, 61	Townsend
	2271	Townsend, 02	Townsend
	4016	Davies, 69	Townsend
	5243	Parr, 71	Townsend
H_2O	1911	Ryzko, 66	Pulse Analysis
	2294	Prasad, 60	Townsend
	2562	Townsend, 03	Townsend
	2933	Bratescu, 50	Townsend
CO_2	948	Bhalla, 60	Townsend
	1445	Schlumbohm, 59	Pulse Analysis
	1625	Schlumbohm, 65	Pulse Analysis
	1724	Schlumbohm, 62	Pulse Analysis
	2387	Schlumbohm, 60	Pulse Analysis
	2593	Townsend, 01	Townsend
	2809	Young, 50	
	2815	Hurst, 06	Townsend
	3435	Conti, 67	Townsend
	3490	Bishop, 11	Townsend
	4843	Baker, 70	Townsend
SO_2	1724	Schlumbohm, 62	Pulse Analysis
	2881	Wheatley, 13	Townsend
SF_6	1260	Bhalla, 62	Townsend
	1724	Schlumbohm, 62	Pulse Analysis
	2558	Hochberg, 42	Townsend
	2595	Hochberg, 46	Townsend
	5053	Boyd, 71	Townsend
CH_4	973	Frommhold, 59	Pulse Analysis
	1161	Davies, 63	Townsend
	1335	Heylen, 63	Townsend
	1445	Schlumbohm, 59	Pulse Analysis
	1625	Schlumbohm, 65	Pulse Analysis
	1836	Cookson, 66	Townsend
	1836	Cookson, 66	Pulse Analysis
	1958	Cookson, 65	Townsend
	1958	Cookson, 65	Pulse Analysis

Ionization Coefficient (Experimental)—*Continued*

	2053	Frommhold, 58	Pulse Analysis
	2387	Schlumbohm, 60	Pulse Analysis
	2466	Cookson, 66	Townsend
	2466	Cookson, 66	Pulse Analysis
	2574	Frommhold, 60	Pulse Analysis
	2934	Giurgea, 55	Townsend
	3177	LeBlanc, 60	Townsend
	5228	McArthur, 70	Pulse Analysis
C_2H_2	1335	Heylen, 63	Townsend
C_2H_4	1335	Heylen, 63	Townsend
C_2H_6	3177	LeBlanc, 60	Townsend
C_3H_8	3177	LeBlanc, 60	Townsend
C_4H_{10}	3177	LeBlanc, 60	Townsend
C_5H_{12}	2595	Hochberg, 46	Townsend
	3177	LeBlanc, 60	Townsend
C_6H_5	2554	Swamy, 67	Townsend
C_6H_6	1625	Schlumbohm, 65	Pulse Analysis
	2931	Badareu, 41	Townsend
	2932	Badareu, 42	Townsend
	2935	Valeriu–Petrescu, 43	Townsend
C_6H_{12}	1445	Schlumbohm, 59	Pulse Analysis
	2387	Schlumbohm, 60	Pulse Analysis
	2935	Valeriu–Petrescu, 43	Townsend
C_6H_{14}	3177	Leblanc, 60	Townsend
C_7H_3	2932	Badareu, 42	Townsend
C_7H_8	2935	Valeriu–Petrescu, 43	Townsend
$CHCl_3$	2595	Hochberg, 46	Townsend
CH_3F	3600	Razzak, 68	Townsend
CH_3Cl	3178	Devins, 60	Townsend
	3600	Razzak, 68	Townsend
CH_3Br	3600	Razzak, 68	Townsend
CH_3OH	1445	Schlumbohm, 59	Pulse Analysis
	2387	Schlumbohm, 60	Pulse Analysis
C_2H_5Cl	2595	Hochberg, 46	Townsend
	3178	Devins, 60	Townsend
C_2H_5Br	2595	Hochberg, 46	Townsend

Ionization Coefficient (Experimental)—*Continued*

C_2H_5OH	2052	Schlumbohm, 58	Pulse Analysis
	2101	Frommhold, 56	Pulse Analysis
	2254	Raether, 37	Pulse Analysis
C_3H_7OH	2554	Swamy, 67	Townsend
C_4H_9OH	3922	Swamy, 66	Townsend
$(C_2H_5)_2O$	1625	Schlumbohm, 65	Pulse Analysis
	2500	Richter, 59	Pulse Analysis
CF_4	3465	Bozin, 68	Townsend
	5051	Naidu, 72	
CCl_4	2300	Howard, 58	Townsend
	2595	Hochberg, 46	Townsend
CCl_2F_2	791	Harrison, 53	Townsend
	1724	Schlumbohm, 62	Pulse Analysis
	2345	Moruzzi, 63	Townsend
	2449	Moruzzi, 63	Townsend
	5229	Boyd, 70	Townsend
CF_3SF_5	791	Harrison, 53	Townsend
C_2F_6	3465	Bozin, 68	Townsend
	5051	Naidu, 72	
C_3F_8	2302	Moruzzi, 63	Townsend
	5051	Naidu, 72	
	5123	Prasad, 70	
C_4F_{10}	3604	Razzak, 68	Townsend
	5051	Naidu, 72	
Organic	1445	Schlumbohm, 59	Pulse Analysis
	1625	Schlumbohm, 65	Pulse Analysis
	2052	Schlumbohm, 58	Pulse Analysis
	2387	Schlumbohm, 60	Pulse Analysis
	2547	Heylen, 61	Townsend
	2576	Heylen, 60	Townsend
	3178	Devins, 60	Townsend
	5052	Naidu, 72	
Air	791	Harrison, 53	Townsend
	1911	Ryzko, 66	Pulse Analysis
	2047	Prasad, 59	Townsend
	2050	Llewellyn–Jones, 52	Townsend
	2052	Schlumbohm, 58	Pulse Analysis
	2053	Frommhold, 58	Pulse Analysis
	2134	Sanders, 32	Townsend
	2271	Townsend, 02	Townsend
	2274	Sanders, 33	Townsend
	2277	Masch, 32	Townsend
	2281	Townsend, 04	Townsend

Ionization Coefficient (Experimental)—*Continued*

	2370	Frommhold, 64	Pulse Analysis
	2388	Dutton, 60	Townsend
	2402	Gill, 21	Townsend
	2407	Dutton, 63	Townsend
	2487	Dutton, 61	Townsend
	2488	Dutton, 63	Townsend
	2528	Dutton, 63	Townsend
	2556	Masch, 32	Townsend
	2557	Paavola, 29	Townsend
	2558	Hochberg, 42	Townsend
	2563	Townsend, 01	Townsend
	2569	Townsend, 03	Townsend
	2570	Davies, 65	Townsend
	2571	Davies, 66	Townsend
	2591	Dutton, 62	Townsend
	2595	Hochberg, 46	Townsend
	2767	Driver, 67	Pulse Analysis
	2881	Wheatley, 13	Townsend
	2882	Horton, 17	Townsend
	2919	Dutton, 67	Townsend
	3184	Dutton, 64	Townsend
	3273	Townsend, 00	Townsend
	3490	Bishop, 11	Townsend
	3553	Gill, 12	Townsend
	3908	Scharfman, 64	A C Breakdown
	4015	Daniel, 69	Townsend
	4085	Daniel, 69	Townsend
	5246	Rao, 71	Townsend
	5610	Bhiday, 70	
Mixture	961	Freely, 64	Townsend
	2247	Hale, 39	Townsend
	2275	Bowls, 38	Townsend
	2287	Penning, 34	
	2294	Prasad, 60	Townsend
	2341	Glotov, 37	Townsend
	2354	Chanin, 65	Townsend
	2355	Kruithof, 37	Townsend
	2407	Dutton, 63	Townsend
	2467	Ryzko, 66	Pulse Analysis
	2493	Chanin, 64	Townsend
	2554	Swamy, 67	Townsend
	2815	Hurst, 06	Townsend
	3171	Gill, 12	Townsend
	3477	Heylen, 68	Townsend
	3478	Heylen, 68	Townsend
	3751	Dutton, 69	Townsend
	3922	Swamy, 66	Townsend
	3956	Yamane, 60	
	4018	Riemann, 44	
	4994	Price, 72	Townsend
	5293	Heylen, 71	Townsend
	5577	Heylen, 71	Townsend

Ionization Coefficient (Theoretical)

	2352	Kihara, 52
	2808	Crowe, 55
	3592	Lucas, 67
He	674	Compton, 18
	771	Dunlop, 49
	1440	Heylen, 63
	2143	Abdelnabi, 53
	2347	Compton, 16
	3752	Thomas, 69
	3897	Itoh, 60
	4057	Bortnik, 65
	4188	Lozanskii, 68
	4621	Lotz, 67
	5490	Englert, 71
	4909	Hughes, 70
	5701	Phelps, 59
He^{+1}	4621	Lotz, 67
Li	4621	Lotz, 67
Li^{+1}	4621	Lotz, 67
Li^{+2}	4621	Lotz, 67
Be	4621	Lotz, 67
Be^{+1}	4621	Lotz, 67
Be^{+2}	4621	Lotz, 67
Be^{+3}	4621	Lotz, 67
B	4621	Lotz, 67
B^{+1}	4621	Lotz, 67
B^{+2}	4621	Lotz, 67
B^{+3}	4621	Lotz, 67
B^{+4}	4621	Lotz, 67
C	4621	Lotz, 67
C^{+1}	4621	Lotz, 67
C^{+2}	4621	Lotz, 67
C^{+3}	4621	Lotz, 67
C^{+4}	4621	Lotz, 67
C^{+5}	4621	Lotz, 67
Ne	1440	Heylen, 63
	2048	Druyvesteyn, 36
	2453	Golant, 57
	2501	Glotov, 38
	3450	Zaitev, 39
	3753	Thomas, 69
	4621	Lotz, 67
	4909	Hughes, 70
	5110	DeHoog, 71
Ne^{+1}	4621	Lotz, 67
Ne^{+2}	4621	Lotz, 67
Ne^{+3}	4621	Lotz, 67
Ne^{+4}	4621	Lotz, 67
Ne^{+5}	4621	Lotz, 67
Ne^{+6}	4621	Lotz, 67
Ne^{+7}	4621	Lotz, 67
Ne^{+8}	4621	Lotz, 67
Ne^{+9}	4621	Lotz, 67
Na	4621	Lotz, 67
Na^{+1}	4621	Lotz, 67
Na^{+2}	4621	Lotz, 67
Na^{+3}	4621	Lotz, 67
Na^{+4}	4621	Lotz, 67
Na^{+5}	4621	Lotz, 67
Na^{+6}	4621	Lotz, 67
Na^{+7}	4621	Lotz, 67
Na^{+8}	4621	Lotz, 67
Na^{+9}	4621	Lotz, 67
Na^{+10}	4621	Lotz, 67
Ar	881	Golant, 59
	1440	Heylen, 63
	2276	Emeleus, 36
	2452	Golant, 57

Ionization Coefficient (Theoretical) — *Continued*

Hg	3266	Klarfeld, 41
	3270	Cayless, 59
H	4621	Lotz, 67
H_2	260	Engelhardt, 63
	767	Aamodt, 63
	927	Lewis, 58
	1638	Heylen, 60
	1723	Muller, 62
	2034	Stuart, 60
	2037	Gerjuoy, 60
	2087	Deas, 49
	2276	Emeleus, 36
	2519	Blevin, 57
	5235	Nasser, 71
	5292	Folkard, 70
D_2	260	Engelhardt, 63
N	4621	Lotz, 67
N_2	218	Engelhardt, 64
	2087	Deas, 49
	2276	Emeleus, 36
	2392	Compton, 16
N^{+1}	4621	Lotz, 67
N^{+2}	4621	Lotz, 67
N^{+3}	4621	Lotz, 67
N^{+4}	4621	Lotz, 67
N^{+5}	4621	Lotz, 67
N^{+6}	4621	Lotz, 67
O	4621	Lotz, 67
O_2	2276	Emeleus, 36
	2553	Hake, 67
O^{+1}	3485	Lotz, 68
	4621	Lotz, 67
O^{+2}	3485	Lotz, 68
	4621	Lotz, 67
O^{+3}	3485	Lotz, 68
	4621	Lotz, 67
O^{+4}	3485	Lotz, 68
	4621	Lotz, 67
O^{+5}	3485	Lotz, 68
	4621	Lotz, 67
O^{+6}	3485	Lotz, 68
	4621	Lotz, 67
O^{+7}	3485	Lotz, 68
	4621	Lotz, 67
O^{+8}	3485	Lotz, 68
F	4621	Lotz, 67
F^{+1}	4621	Lotz, 67
F^{+2}	4621	Lotz, 67
F^{+3}	4621	Lotz, 67
F^{+4}	4621	Lotz, 67
F^{+5}	4621	Lotz, 67
F^{+6}	4621	Lotz, 67
F^{+7}	4621	Lotz, 67
F^{+8}	4621	Lotz, 67
HCl	2392	Compton, 16
H_2O	2392	Compton, 16
CO_2	2392	Compton, 16
	2553	Hake, 67
C_2H_4	1335	Heylen, 63
Air	2087	Deas, 49
	2276	Emeleus, 36
Mixture	2096	Kruithof, 37
	2501	Glotov, 38
	3552	Moralew, 37
	4909	Hughes, 70
	5239	Lozanskii, 71

Ionization Coefficient in Crossed Fields (Experimental)

H_2	238	Fletcher, 66	
	2162	Haydon, 63	
	2468	Fletcher, 66	
	2539	Bernstein, 62	
	2580	Haydon, 62	Townsend
	2588	Haydon, 62	Townsend
N_2	238	Fletcher, 66	
	2448	Bagnall, 65	
	2468	Fletcher, 66	
Air	2231	Bhiday, 67	
	5610	Bhiday, 70	

Ionization Coefficient in Crossed Fields (Theoretical)

2450	Somerville, 52	H_2	2303	Blevin, 63
			2325	Blevin, 58

Ionization Coefficient, High Frequency (Experimental)

He	2184	Macdonald, 49	Air	2188	Herlin, 48
				2405	Herlin, 48
H_2	2157	Macdonald, 49		3606	Taylor, 68

Ionization Coefficient, High Frequency (Theoretical)

He	2184	Macdonald, 49	H_2	2157	Macdonald, 49

Recombination Coefficient (Experimental)

He	249	Chen, 61	Radiation
	596	Biondi, 49	Plasma Decay, Microwave
	661	Mittelstadt, 63	Plasma Decay, Microwave
	673	Oskam, 63	Plasma Decay, Microwave
	759	Robben, 63	Radiation
	802	Johnson, 50	Plasma Decay, Microwave
	802	Johnson, 50	Radiation
	815	Newton, 66	Plasma Decay, Microwave
	1639	Hinnov, 62	Plasma Decay, Microwave
	1639	Hinnov, 62	Radiation
	1642	Sexton, 58	Plasma Decay, Microwave
	1671	Leycuras, 63	
	1713	Kuckes, 61	Plasma Decay, Microwave
	1870	Anisimov, 66	Plasma Decay, Microwave
	1901	Jeffries, 65	Radiation
	1961	Gusinow, 66	Plasma Decay
	1963	Stafford, 66	Plasma Decay, Microwave
	1963	Stafford, 66	Radiation
	2230	Craggs, 63	Radiation
	2329	Anderson, 62	Plasma Decay, Microwave
	2329	Anderson, 62	Radiation
	2330	Hinnov, 62	Plasma Decay, Microwave

Recombination Coefficient (Experimental)—*Continued*

	2330	Hinnov, 62	Radiation
	2331	Motley, 62	Plasma Decay, Microwave
	2447	Aleskovskii, 63	Plasma Decay, Probe
	2447	Aleskovskii, 63	Radiation
	2456	Thomas, 66	Plasma Decay, Microwave
	2549	Fugol, 66	Radiation
	3312	Robben, 67	Plasma Decay, Probe
	3312	Robben, 67	Plasma Decay, Radiation
	3464	Born, 68	Plasma Decay, Microwave
	3658	Newton, 68	Plasma Decay, Microwave
	3795	Davidson, 62	Plasma Decay, Microwave
	4193	Golant, 63	Plasma Decay, Microwave
	4374	Berlande, 70	Plasma Decay, Microwave
	4586	Chen, 69	Plasma Decay, Microwave
	5134	Delpech, 72	Plasma Decay, Microwave
	5184	Aizentson, 72	Plasma, Steady State
	5232	Donovan, 71	Plasma Decay, Microwave
	5325	Johnson, 72	Plasma Decay, Microwave
	5327	Stevefelt, 72	Radiation
	5327	Stevefelt, 72	Plasma Decay, Radiation
	5343	Boulmer, 73	Plasma Decay, Microwave
	5488	Johnson, 73	Plasma Decay, Microwave
	5501	Cronin, 70	Plasma Decay, Microwave
	5533	Baravian, 72	Radiation
	5570	Johnson, 72	Plasma Decay, Microwave
	5730	Johnson, 71	Plasma Decay, Microwave
	5745	Chen, 69	Plasma Decay, Microwave
	5745	Chen, 69	Plasma Decay, Probe
	5772	Collins, 70	Plasma Decay, Microwave
	5772	Collins, 70	Plasma Decay, Radiation
He^{+1}	883	Mosberg, 66	Plasma Decay, Microwave
	883	Mosberg, 66	Plasma Decay, Probe
	883	Mosberg, 66	Radiation
He^{+2}	883	Mosberg, 66	Plasma Decay, Microwave
	883	Mosberg, 66	Plasma Decay, Probe
	883	Mosberg, 66	Radiation
	1766	Hinnov, 66	Plasma Decay, Microwave
	1766	Hinnov, 66	Radiation
He_3^{+1}	5203	Gerardo, 71	Plasma Decay, Microwave
C	5294	Dunn, 71	Plasma Decay, Microwave
	5294	Dunn, 71	Plasma Decay, Probe
Ne	217	Holt, 50	Plasma Decay, Microwave
	217	Holt, 50	Radiation
	584	Hess, 65	Plasma Decay, Microwave
	758	Biondi, 63	Plasma Decay, Microwave
	758	Biondi, 63	Radiation
	1363	Biondi, 49	Plasma Decay, Microwave
	1600	Connor, 65	Plasma Decay, Microwave
	2169	Oskam, 58	Plasma Decay, Microwave
	2409	Hess, 64	Plasma Decay, Microwave
	3443	Frommhold, 68	Plasma Decay, Microwave

Recombination Coefficient (Experimental) — *Continued*

	4585	Cunningham, 69	Plasma Decay, Probe
	4586	Chen, 69	Plasma Decay, Microwave
	5745	Chen, 69	Plasma Decay, Microwave
	5745	Chen, 69	Plasma Decay, Probe
	5775	Olsen, 52	Plasma Decay, Radiation
Ne_2^{+1}	661	Mittelstadt, 63	Plasma Decay, Microwave
	673	Oskam, 63	Plasma Decay, Microwave
	1344	Biondi, 64	Plasma Decay, Microwave
	2988	Kasner, 67	Plasma Decay, Microwave
	3483	Kasner, 68	Plasma Decay, Microwave
	4044	Philbrick, 69	Plasma Decay, Microwave
Ar	252	Redfield, 51	Plasma Decay, Microwave
	252	Redfield, 51	Radiation
	355	Kenty, 28	Plasma Decay, Probe
	711	Sexton, 60	Plasma Decay, Microwave
	758	Biondi, 63	Plasma Decay, Microwave
	758	Biondi, 63	Radiation
	811	Kretschmer, 62	Plasma Decay, Probe
	1363	Biondi, 49	Plasma Decay, Microwave
	1642	Sexton, 58	Plasma Decay, Microwave
	1786	Kozlov, 65	
	1872	Luhr, 31	
	1873	Fox, 66	Plasma Decay, Probe
	1961	Gusinow, 66	Plasma Decay
	2111	Luhr, 30	
	2230	Craggs, 63	Radiation
	2270	Marshall, 29	
	3277	Trong, 67	Radiation
	3433	Aleksandrov, 68	Radiation
	3438	Fox, 67	Plasma Decay, Probe
	3468	Funahashi, 68	Plasma Decay, Microwave
	4065	Mehr, 68	Plasma Decay, Microwave
	4585	Cunningham, 69	Plasma Decay, Probe
	4586	Chen, 69	Plasma Decay, Microwave
	5184	Aizentson, 72	Plasma, Steady State
	5240	Hughes, 71	Radiation
	5242	Novikova, 71	Plasma, Steady State
	5745	Chen, 69	Plasma Decay, Microwave
	5745	Chen, 69	Plasma Decay, Probe
	5775	Olsen, 52	Plasma Decay, Radiation
	5776	Mitin, 69	Plasma Decay, Radiation
	5777	Van Trong, 67	Plasma Decay, Radiation
	5782	Desai, 69	Radiation
Ar_2^{+1}	661	Mittelstadt, 63	Plasma Decay, Microwave
	673	Oskam, 63	Plasma Decay, Microwave
K	2546	D'Angelo, 61	Plasma, Steady State
Kr	3188	Popov, 60	
	5128	Cunningham, 72	Plasma Decay, Probe
	5184	Aizentson, 72	Plasma, Steady State
	5745	Chen, 69	Plasma Decay, Microwave
	5745	Chen, 69	Plasma Decay, Probe

Recombination Coefficient (Experimental)—*Continued*

	5776	Mitin, 69	Plasma Decay, Radiation
Kr_2^{+1}	673	Oskam, 63	Plasma Decay, Microwave
Xe	860	Chantry, 64	Plasma Decay, Microwave
	2130	Brodskii, 66	Plasma Decay, Microwave
	5745	Chen, 69	Plasma Decay, Microwave
	5745	Chen, 69	Plasma Decay, Probe
	5776	Mitin, 69	Plasma Decay, Radiation
Xe_2^{+1}	673	Oskam, 63	Plasma Decay, Microwave
Cs	638	Wada, 63	Plasma, Steady State
	697	Wada, 61	Plasma, Steady State
	737	Aleskovskii, 63	Plasma Decay, Probe
	737	Aleskovskii, 63	Radiation
	807	Kretschmer, 63	Plasma Decay, Probe
	811	Kretschmer, 62	Plasma Decay, Probe
	1620	Hammer, 66	
	1634	Harris, 65	
	1737	Dandurand, 51	Plasma Decay, Microwave
	2400	Mohler, 29	Radiation
	2457	Balfour, 66	Plasma Decay, Microwave
	2546	D'Angelo, 61	Plasma, Steady State
	2590	Knechtli, 62	Plasma, Steady State
	2950	Mohler, 37	Plasma Decay, Probe
	2950	Mohler, 37	Radiation
	2983	Harris, 68	Plasma Decay, Microwave
	3555	Mohler, 33	Radiation
	3609	Von Goeler, 68	
	3650	David, 67	Radiation
	5231	Archambault, 71	Plasma Decay, Microwave
Hg	807	Kretschmer, 63	Plasma Decay, Probe
	811	Kretschmer, 62	Plasma Decay, Probe
	1729	Dandurand, 51	Plasma Decay, Microwave
	1729	Dandurand, 51	Radiation
	2395	Biondi, 53	Plasma Decay, Microwave
	2518	Mohler, 37	Plasma Decay, Probe
	3613	Skrebov, 67	Radiation
	3654	Egorov, 67	Radiation
H	241	Fowler, 59	Radiation
	346	Craggs, 47	Radiation
	1639	Hinnov, 62	Plasma Decay, Microwave
	1639	Hinnov, 62	Radiation
	5778	Brand, 69	Plasma Decay, Microwave
	5778	Brand, 69	Plasma Decay, Radiation
	5779	Irons, 65	Plasma Decay, Radiation
H_2	239	Persson, 55	Plasma Decay, Microwave
	240	Varnerin, 51	Plasma Decay, Microwave
	406	Craggs, 46	Radiation
	1240	Whitmer, 56	Plasma Decay, Microwave
	1363	Biondi, 49	Plasma Decay, Microwave

Recombination Coefficient (Experimental) — *Continued*

	1389	Cooper, 65	Radiation
	1872	Luhr, 31	
	2038	Litvak, 66	Radiation
	2106	Craggs, 47	Radiation
	2111	Luhr, 30	
	2230	Craggs, 63	Radiation
	2292	Richardson, 51	Plasma Decay, Microwave
	3278	Trong, 67	Radiation
	5500	Cronin, 70	Plasma Decay, Microwave
	5697	Janssen, 72	Radiation
N_2	703	Bialecke, 58	Plasma Decay, Microwave
	728	Mentzoni, 63	Plasma Decay, Microwave
	807	Kretschmer, 63	Plasma Decay, Probe
	811	Kretschmer, 62	Plasma Decay, Probe
	1363	Biondi, 49	Plasma Decay, Microwave
	1399	Faire, 59	Plasma Decay, Microwave
	1872	Luhr, 31	
	2111	Luhr, 30	
	2372	Van Lint, 64	Plasma Decay, Microwave
	2394	Hackam, 65	Plasma Decay, Microwave
	3166	Bryan, 57	
	4064	Bromer, 68	Plasma Decay, Microwave
	4605	Sayers, 58	Plasma Decay, Probe
N_2^{+1}	1247	Kasner, 65	Plasma Decay, Microwave
	1344	Biondi, 64	Plasma Decay, Microwave
	1605	Kasner, 61	Plasma Decay, Microwave
	2455	Biondi, 66	Plasma Decay, Microwave
	2993	Kasner, 67	Plasma Decay, Microwave
	4045	Mehr, 69	Plasma Decay, Microwave
	4681	Sayers, 56	Plasma Decay, Probe
	5124	Mahdavi, 71	Plasma Decay, Probe
N_4^{+1}	1247	Kasner, 65	Plasma Decay, Microwave
	1344	Biondi, 64	Plasma Decay, Microwave
O_2	807	Kretschmer, 63	Plasma Decay, Probe
	811	Kretschmer, 62	Plasma Decay, Probe
	1363	Biondi, 49	Plasma Decay, Microwave
	1601	Anisimov, 64	Plasma Decay, Microwave
	1872	Luhr, 31	
	2111	Luhr, 30	
	3428	Mentzoni, 65	Plasma Decay, Microwave
	3786	Smith, 68	Plasma Decay, Probe
	4605	Sayers, 58	Plasma Decay, Probe
	5699	Bragin, 70	Plasma Decay, Microwave
O_2^{+1}	1344	Biondi, 64	Plasma Decay, Microwave
	1605	Kasner, 61	Plasma Decay, Microwave
	3611	Kasner, 68	Plasma Decay, Microwave
	4045	Mehr, 69	Plasma Decay, Microwave
	5124	Mahdavi, 71	Plasma Decay, Probe
	5198	Plumb, 72	Plasma Decay, Probe
O_4^{+1}	3611	Kasner, 68	Plasma Decay, Microwave

Recombination Coefficient (Experimental) — *Continued*

	5198	Plumb, 72	Plasma Decay, Probe
CO	3601	Mentzoni, 68	Plasma Decay, Microwave
	5294	Dunn, 71	Plasma Decay, Microwave
	5294	Dunn, 71	Plasma Decay, Probe
	5783	Mentzoni, 69	Plasma Decay, Microwave
NO	658	Gunton, 63	Plasma Decay, Microwave
	840	Young, 66	
	920	Doering, 62	Plasma Decay, Probe
	920	Doering, 62	Plasma, Steady State
	1181	Gunton, 61	Plasma Decay, Microwave
	2491	Stein, 64	Plasma Decay, Microwave
	3229	Mentzoni, 67	Plasma Decay, Microwave
	4789	Lin, 63	
NO^{+1}	1609	Gunton, 65	Plasma Decay, Microwave
	3610	Weller, 68	Plasma Decay, Microwave
	5124	Mahdavi, 71	Plasma Decay, Probe
H_2O	1450	Takeda, 60	Plasma Decay, Microwave
$CO_2{}^{+1}$	2986	Weller, 67	Plasma Decay, Microwave
	5124	Mahdavi, 71	Plasma Decay, Probe
$(NO)_2{}^{+1}$	3610	Weller, 68	Plasma Decay, Microwave
Air	1872	Luhr, 31	
	2111	Luhr, 30	
	5699	Bragin, 70	Plasma Decay, Microwave
Mixture	254	Richardson, 52	Plasma Decay, Microwave
	254	Richardson, 52	Radiation
	698	Faire, 58	Plasma Decay, Microwave
	705	Cool, 66	Radiation
	758	Biondi, 63	Plasma Decay, Microwave
	758	Biondi, 63	Radiation
	860	Chantry, 64	Plasma Decay, Microwave
	1605	Kasner, 61	Plasma Decay, Microwave
	2029	Morgulis, 66	Plasma Decay, Probe
	2169	Oskam, 58	Plasma Decay, Microwave
	2230	Craggs, 63	Radiation
	2268	Wilson, 67	Plasma Decay, Microwave
	2445	Lennon, 59	Plasma Decay, Microwave
	2550	Polushkin, 67	Plasma Decay, Probe
	2551	Morgulis, 66	Plasma Decay, Probe
	3229	Mentzoni, 67	Plasma Decay, Microwave
	3434	Braun, 67	Plasma, Steady State
	5291	Veatch, 70	Radiation

Recombination Coefficient (Theoretical)

	444	Bates, 62
	595	Abramov, 66
	640	Makin, 63
	966	Bates, 50
	975	Aptekar, 56
	1258	Burgess, 64
	1606	Makin, 64
	1614	D'Angelo, 65
	1615	Collins, 65
	1647	Gurevich, 64
	2165	Pitaevskii, 62
	2272	Biberman, 63
	2498	Thomson, 24
	2885	Smirnov, 67
	2991	Veselovskii, 67
	3311	Janev, 67
	3469	Drawin, 68
He	972	Byron, 62
	998	Kingston, 64
	3437	Deloche, 67
	3653	Deloche, 68
	5130	Drawin, 72
	5732	Drawin, 71
	5745	Chen, 69
	5761	Mansbach, 69
	5773	Collins, 68
	5774	Deloche, 68
He^{+1}	715	Burgess, 60
	1259	Bates, 65
	2168	Bates, 64
	3381	Bates, 67
	5288	Shore, 69
He^{+2}	2259	Seaton, 60
He_2^{+1}	1675	Warke, 66
Li^{+1}	1259	Bates, 65
Li^{+2}	5288	Shore, 69
Be^{+1}	5288	Shore, 69
Be^{+3}	5288	Shore, 69
B^{+2}	5288	Shore, 69
B^{+4}	5288	Shore, 69
C	5289	Landini, 71
	5350	Tarter, 71
C^{+1}	5288	Shore, 69
C^{+3}	5288	Shore, 69
C^{+5}	4891	Bain, 71
	5288	Shore, 69
Ne	5289	Landini, 71
	5350	Tarter, 71
	5745	Chen, 69
Ne^{+9}	4891	Bain, 71
Na^{+1}	1259	Bates, 65
Mg	5289	Landini, 71
	5350	Tarter, 71
Mg^{+1}	5288	Shore, 69
Al^{+2}	5288	Shore, 69
Si	5289	Landini, 71
Si^{+3}	5288	Shore, 69
S	5289	Landini, 71
Ar	5201	Wanless, 71
	5745	Chen, 69
Ar^{+1}	3180	Dugan, 66
K	5781	Curry, 70
K^{+1}	1259	Bates, 65
Ca	5289	Landini, 71
Ca^{+1}	5288	Shore, 69
Fe	5289	Landini, 71
Kr	5745	Chen, 69
Xe	5745	Chen, 69
Cs	737	Aleskovskii, 63
	3536	Abramov, 65
	3598	Norcross, 68
	5698	Shaw, 71
	5761	Mansbach, 69
	5781	Curry, 70
Cs^{+1}	1805	Norcross, 66
	3180	Dugan, 66

Recombination Coefficient (Theoretical)—*Continued*

H	601	Seaton, 59
	5350	Tarter, 71
	5761	Mansbach, 69
	5781	Curry, 70
H_2	4604	Bates, 71
H^{+1}	146	Bates, 62
	731	D'Angelo, 61
	972	Byron, 62
	994	Bates, 64
	998	Kingston, 64
	1010	Stueckelberg, 30
	1602	Boardman, 64
	2031	Bates, 61
	2147	Bates, 64
	2259	Seaton, 60
	2390	Burgess, 58
	2527	Stabler, 63
	4656	Bates, 62
H_2^{+1}	358	Zanstra, 46
	1665	Wilkins, 66
	3471	Dubrovskii, 67
N	5289	Landini, 71
	5350	Tarter, 71
N_2	750	Bates, 62
	4604	Bates, 71
N_2^{+1}	1675	Warke, 66
N^{+4}	5288	Shore, 69
N^{+6}	5288	Shore, 69
O	5289	Landini, 71
	5350	Tarter, 71
O_2	750	Bates, 62
O^{+1}	243	Bates, 39
	1180	Massey, 43
O_2^{+1}	1675	Warke, 66
	4020	Chan, 68
O^{+5}	5288	Shore, 69
O^{+7}	4891	Bain, 71
	5288	Shore, 69
NO^{+1}	3462	Bardsley, 68
	3476	Hansen, 68
CO_2	4604	Bates, 71
Mixture	3651	Dalidchik, 67
	4604	Bates, 71

Energy Distribution (Experimental)

He	1651	Roberts, 66
	1800	Bocchieri, 66
	1818	Kagan, 66
	1822	Borodin, 66
	1896	Bond, 65
	1899	Roberts, 65
	2098	Borodin, 67
	2163	Borodin, 65
	2236	Vorobeva, 65
	2469	Vorobeva, 66
	3174	Twiddy, 61
	3231	Kagan, 65
	3442	Franklin, 68
	3482	Koons, 68
	3504	Emeleus, 36
	3649	Borodin, 67
	3792	Pfau, 67
Ne	1800	Bocchieri, 66
	1818	Kagan, 66
	1896	Bond, 65
	2236	Vorobeva, 65
	2469	Vorobeva, 66
	2530	Crawford, 63
	2807	VanGorcum, 36
	2887	Afanaseva, 67
	3174	Twiddy, 61
	3231	Kagan, 65
	3235	Medicus, 56
	3442	Franklin, 68
	3496	Druyvesteyn, 30
	3603	Rayment, 67
	3608	Vagner, 68
	3679	Heymann, 68
	3792	Pfau, 67
	3797	Fields, 63
	3951	Twiddy, 63
Ar	1800	Bocchieri, 66
	2568	Sloane, 33
	2886	Kagan, 67
	3169	Haigh, 50
	3174	Twiddy, 61
	3185	Haigh, 52

Energy Distribution (Experimental)—*Continued*

	3442	Franklin, 68
	3470	Drouet, 68
	3496	Druyvesteyn, 30
	3679	Heymann, 68
	3792	Pfau, 67
	3797	Fields, 63
	5191	Losee, 72
Kr	1837	Barnes, 66
	3951	Twiddy, 63
Xe	1837	Barnes, 66
	3233	Wehner, 52
	3790	Aisenberg, 64
Hg	2008	Vorobeva, 63
	2019	Vorobeva, 64
	2469	Vorobeva, 66
	3168	Kagan, 67
	3231	Kagan, 65
	3288	Malyshev, 53
	3306	Rayment, 68
	3489	Langmuir, 24
	3895	Guseva, 51
	3951	Twiddy, 63
	4189	Kagan, 51
H_2	2538	Boyd, 67
	3173	Boyd, 59
	3175	Boyd, 60
	3716	Boyd, 54
	3951	Twiddy, 63
	5573	Kenny, 70
N_2	693	Noon, 66
	2521	Thompson, 61
	2584	Swift, 62
	3185	Haigh, 52
	3299	Kilvington, 67
	3597	Noon, 68
O_2	2521	Thompson, 61
	3172	Boyd, 59
CO	2494	Chao, 45
Air	2442	Badareu, 58
	2494	Chao, 45
	3169	Haigh, 50
	3185	Haigh, 52
Mixture	1837	Barnes, 66
	2028	Afanaseva, 66
	2344	Vorobeva, 64
	2469	Vorobeva, 66
	2887	Afanaseva, 67
	3168	Kagan, 67
	3231	Kagan, 65
	3599	Ostapchenko, 68
	3614	Kagin, 68
	3951	Twiddy, 63
	4094	Malakhov, 67

Energy Distribution (Theoretical)

761	Parker, 63
927	Lewis, 58
1309	Ross, 67
1388	Morse, 35
1420	Holstein, 46
1441	Druyvesteyn, 30
1789	Sodha, 66
1860	Townsend, 33
2043	Bowe, 63
2044	Pidduck, 13
2094	Davydov, 35
2152	Wu, 61
2185	Margenau, 58
2192	Margenau, 48
2193	Margenau, 48
2196	Didlaukis, 33
2197	Druyvesteyn, 32
2225	Townsend, 36
2297	Dreicer, 60
2307	Cahn, 49
2323	Lichtenstein, 38
2324	Druyvesteyn, 34
2337	Davydov, 36
2340	Davydov, 37
2348	Kagan, 61
2352	Kihara, 52
2369	Haseltine, 39
2393	Compton, 16
2436	Cahn, 49
2437	Shkarofsky, 61
2515	Rose, 55
2540	Kelly, 60
2583	Wu, 62
2806	Pearson, 63
3156	Kagan, 64
3170	Yarnold, 45
3228	Brown, 66
3235	Medicus, 56
3242	Stenflo, 66
3261	Ulyanov, 64
3263	Ornstein, 36
3276	Peyraud, 67

Energy Distribution (Theoretical)—*Continued*

	3281	Ornstein, 36
	3284	Bayet, 56
	3285	Bayet, 56
	3287	Ulyanov, 66
	3290	Bayet, 55
	3308	Soshnikov, 68
	3310	Stiller, 68
	3314	Yen, 68
	3430	Caldirola, 66
	3493	Kovrizhnykh, 60
	3538	Didlaukis, 32
	3592	Lucas, 67
	3594	Lo Surdo, 68
	3605	Sonin, 68
	3615	Nastoyashchii, 68
	3648	De Hoog, 68
	3661	Allouche, 68
	3678	Peyraud, 68
	3893	Gurevich, 57
	3894	Gurevich, 57
	3898	Jancel, 54
	3907	Sampson, 63
	3911	Sengupta, 61
He	397	Barbiere, 51
	1208	Reder, 54
	1297	Llewellyn-Jones, 36
	1440	Heylen, 63
	2010	Smit, 36
	2045	Dunlop, 51
	2143	Abdelnabi, 53
	2184	Macdonald, 49
	2194	Hartman, 48
	3463	Bell, 68
	3714	Elkomoss, 68
	3792	Pfau, 67
	4056	Postma, 70
	4057	Bortnik, 65
Ne	700	Salmon, 63
	1440	Heylen, 63
	2194	Hartman, 48
	2453	Golant, 57
	2454	Kagan, 60
	3157	Kagan, 62
	3534	Kagan, 62
	3791	Rutscher, 67
	3792	Pfau, 67
Ar	292	Engelhardt, 64
	397	Barbiere, 51
	881	Golant, 59
	1440	Heylen, 63
	2452	Golant, 57
	2454	Kagan, 60
	3157	Kagan, 62
	3479	Jancel, 68
	3792	Pfau, 67
Cs	3305	Postma, 68
Hg	2454	Kagan, 60
	3157	Kagan, 62
H_2	260	Engelhardt, 63
	756	Baraff, 63
	1043	Frost, 62
	1638	Heylen, 60
	1723	Muller, 62
	2037	Gerjuoy, 60
	2113	Allis, 52
	2157	Macdonald, 49
	2470	Hantzsche, 66
	2589	Stuart, 62
	3241	Hantzsche, 66
	3463	Bell, 68
	5224	Haydon, 70
D_2	260	Engelhardt, 63
N_2	1043	Frost, 62
	3463	Bell, 68
	5233	Kline, 71
Air	1207	Carleton, 62
Mixture	292	Engelhardt, 64
	3593	LoSurdo, 67
	3902	Lyman, 66
	3952	Uman, 64

Conductivity (Experimental)

	2928	Ionescu, 31
He	306	Anderson, 55
	312	Phelps, 51
	314	Gould, 54
	3179	Maksimov, 67
	3554	Clay, 37
	5327	Stevefelt, 72
Ne	312	Phelps, 51
	3554	Clay, 37
	3556	Clay, 37
	3679	Heymann, 68
	3950	Tanaca, 64
	4021	Aleksandrov, 63

Conductivity (Experimental)—*Continued*

Ar	312	Phelps, 51
	2018	Hamberger, 68
	2819	Fedulov, 66
	3167	Lin, 55
	3245	Golubev, 64
	3269	Maecker, 60
	3380	Bues, 67
	3440	Ciampi, 67
	3480	Konjevic, 68
	3679	Heymann, 68
	3950	Tanaca, 64
Kr	312	Phelps, 51
Xe	312	Phelps, 51
	2018	Hamberger, 68
	2472	Zauderer, 66
	3554	Clay, 37
	3556	Clay, 37
Cs	149	Mirlin, 62
	3202	Nighan, 67
	3429	Mohler, 38
Hg	3309	Shimahara, 68
	3793	Prime, 52
H_2	312	Phelps, 51
	1559	Brasefield, 30
	2018	Hamberger, 68
	3466	Chiplonkar, 68
	3657	Bono, 67
N_2	312	Phelps, 51
	693	Noon, 66
	2232	Formato, 60
	2586	Formato, 62
	3181	Valentin, 67
	3269	Maecker, 60
	3282	Christmann, 67
	3473	Fauchais, 68
O_2	2586	Formato, 62
	3494	Carruthers, 62
NO	1779	Mentzoni, 66
H_2O	305	Maecker, 55
CO_2	3383	Gupta, 67
Air	2321	Childs, 32
	2926	Appleton, 32
	3161	Lamb, 57
	3164	Krinberg, 65
	3302	Morsell, 67
	3383	Gupta, 67
	3494	Carruthers, 62
	3497	Szekely, 29
	3535	Finkelnburg, 50
	3539	Karpenko, 52
	3540	Appleton, 35
	3713	Cottereau, 68
	3721	Ionescu, 35
	3953	Valentin, 67
Mixture	1473	Harris, 63
	2472	Zauderer, 66
	2579	Dutt, 60
	2818	Khozhatelev, 66
	3164	Krinberg, 65
	3244	Morgulis, 66
	3245	Golubev, 64
	3291	Veyssiere, 67
	3302	Morsell, 67
	3427	Harris, 64
	3439	Bernard, 67
	3444	Fells, 67
	3445	Goldenberg, 67
	3458	Ellington, 68
	3461	Brederlow, 68
	3474	Garrison, 68
	3481	Koyama, 67
	3529	Goldenberg, 64
	3537	Donskoi, 63
	3539	Karpenko, 52
	3596	Maslennikov, 67
	3677	Schwenn, 68
	3789	Akimov, 66
	3794	Croitoru, 63
	3892	Goldenberg, 64
	3900	Kerrebrock, 64
	3904	Mullaney, 61
	3955	Zukoski, 64
	3958	Zukoski, 65

Conductivity (Theoretical)

2183	Chambers, 52
2185	Margenau, 58
2187	Huxley, 51
2255	Huxley, 57
2437	Shkarofsky, 61
2471	Delcroix, 66
2473	Dolique, 66
2524	Mallozzi, 63
2540	Kelly, 60
2592	Croitoru, 62

Conductivity (Theoretical)—*Continued*

	2884	Schweitzer, 67
	3155	Epstein, 60
	3158	Cowling, 45
	3182	Bayet, 54
	3237	De Barbieri, 67
	3238	De Barbieri, 67
	3274	Demetriades, 66
	3286	Bayet, 56
	3289	Johnson, 67
	3298	Joyce, 67
	3440	Ciampi, 67
	3492	Schirmer, 58
	3602	Schweitzer, 67
	3655	Hassan, 68
	3660	Alievskii, 67
	3717	Stark, 00
	3796	Devoto, 66
	3893	Gurevich, 57
	3898	Jancel, 54
	3899	Kerrebrock, 64
	3905	Nastoyashchii, 63
	3906	Pustovoit, 63
	3907	Sampson, 63
	3911	Sengupta, 61
	3954	Wilhelm, 66
	3957	Yoshikawa, 62
He	2199	Molmud, 59
	3301	Devoto, 68
Ne	2453	Golant, 57
	3307	Schweitzer, 67
	3441	De Barbieri, 68
Ar	2452	Golant, 57
	3307	Schweitzer, 67
	3798	Devoto, 67
	3799	Devoto, 67
Kr	3307	Schweitzer, 67
Xe	3307	Schweitzer, 67
Cs	1828	Eastlund, 66
H_2	3718	Stark, 01
N_2	3279	Manheimer–Timnat, 59
	3718	Stark, 01
H_2O	2199	Molmud, 59
UF_6	3300	Kudrin, 67
Air	2199	Molmud, 59
	2203	Phelps, 60
	3279	Manheimer–Timnat, 59
	3903	Margenau, 59
Mixture	3227	Kasabov, 66
	3491	Frost, 61
	3646	Viegas, 68
	3787	Shelton, 66
	3909	Schweitzer, 67
	3910	Schweitzer, 66

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7. List of Symbols and Units

Coefficient or Parameter	Symbol	Units
1. (a) Drift velocity	W	cm s^{-1}
(b) Magnetic drift velocity	W_M	cm s^{-1}
(c) Mobility	μ	cm^2 V^{-1} s^{-1}
(d) Magnetic deflection coefficient	ψ	
2. (a) (Drift velocity)/(Diffusion coefficient)	W/D	cm^{-1}
(b) (Diffusion coefficient)/(Mobility)	D/μ	V
(c) Characteristic energy	$\epsilon_k = e\dfrac{D}{\mu}$	eV
(d) Townsend energy factor	k	
3. (a) Diffusion coefficient	D	cm^2 s^{-1}
(b) Thermal equilibrium diffusion coefficient	D_{th}	cm^2 s^{-1}
(c) Diffusion coefficient parallel to the electric field	D_L	cm^2 s^{-1}
(d) Diffusion coefficient perpendicular to the electric field	D_T	cm^2 s^{-1}
4. (a) Attachment coefficient	η	cm^{-1}
(b) Two-body attachment coefficient	η_2	cm^{-1}
(c) Three-body attachment coefficient	η_3	cm^{-1}
(d) Attachment rate coefficient	a	cm^3 s^{-1}
(e) Two-body attachment rate coefficient	a_2	cm^3 s^{-1}
(f) Three-body attachment rate coefficient	a_3	cm^6 s^{-1}
(g) Attachment probability	h	
5. (a) Detachment coefficient	δ	cm^{-1}
(b) Detachment rate coefficient	d	cm^3 s^{-1}
(c) Two-body detachment rate coefficient	d_2	cm^3 s^{-1}

Coefficient or Parameter	Symbol	Units
6. (a) Excitation coefficient	ϵ	cm^{-1}
(b) Excitation coefficient to radiating states	ϵ_r	cm^{-1}
(c) Excitation coefficient to dissociating states (dissociation coefficient)	ϵ_d	cm^{-1}
(d) Excitation rate coefficient	e_2	cm^3 s^{-1}
7. (a) Ionization coefficient	α	cm^{-1}
(b) Apparent ionization coefficient	λ_I	cm^{-1}
(c) Ionization rate coefficient	i	cm^3 s^{-1}
(d) Collisional radiative ionization rate coefficient	i_c	cm^3 s^{-1}
(e) Ionization frequency	ν_i	s^{-1}
8. (a) Two-body recombination rate coefficient	r_2	cm^3 s^{-1}
(b) Three-body recombination rate coefficient	r_3	cm^6 s^{-1}
(c) Decay rate coefficient	g	cm^3 s^{-1}
(d) Collisional radiative decay rate coefficient	g_c	cm^3 s^{-1}
(e) Collisional radiative recombination rate coefficient	r_c	cm^3 s^{-1}
(f) Effective recombination rate coefficient	r_e	cm^3 s^{-1}
9. Gas number density	N	cm^{-3}
10. (a) (Electric field)/(Gas number density)	E/N	V cm^2 (= 10^{17} Td)
(b) (Electric field)/(Gas pressure reduced to 0 °C)	E/p_0	V cm^{-1} $Torr^{-1}$

$(E/N(\text{V cm}^2) = 2.82\times10^{-17}\ E/p_0(\text{V cm}^{-1}\ \text{Torr}^{-1}))$

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