THE ABSORPTION COEFFICIENT FOR SLOW ELECTRONS IN GASES

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Abstract

The absorption coefficient has been measured in H_2, He, A, Ne, N_2, and CO for electrons with velocities corresponding to from 0.5 to 400 volts. As a result of the high resolving power of the apparatus fine structure was found in the curves of all the gases. A minimum in the absorption coefficient curve was found in every case at velocities between 0.7 and 1.1 $(\text{volts})^{1/2}$. A lack of agreement between the present measurements at velocities below 2 volts and recent results of Ramsauer and Kollath appears to be due to a difference of about 0.5 volts in the velocity scales of the two sets of observations.

THE absorption coefficients for slow electrons in hydrogen, helium, argon, neon, nitrogen, and carbon monoxide have been rather definitely established by the investigations of Ramsauer,[1,2] Brode,[3] and Bruche.[4,5,6] Measurements in each of these gases have been made by two or more observers. The object in redetermining the absorption coefficient curves for these gases was two-fold: first to detect any fine structure in the curves which might be brought out by the use of an apparatus having a velocity resolving power higher than had previously been used, and second to extend the measurements as far as possible into the low velocity region.

Apparatus and Method

The apparatus and method employed in this experiment were essentially the same as used by Brode in determining the absorption coefficient in gases.[3] The apparatus used in producing the electron beam was the one used by Brode in his determinations of the absorption coefficient in mercury[7] and the alkali metal vapors.[8] Except for the tungsten filament the apparatus was constructed entirely of tantalum. The electron source was a 3 mil tungsten filament placed along the axis of a cylinder 7 mm in diameter. The electrons were accelerated to the cylinder. A narrow beam of these electrons passed through a longitudinal slit 0.2 mm wide and 5 mm high in the cylinder, and was bent by a magnetic field into a circular path defined by a system of

[1] C. Ramsauer, Ann. d. Physik **64**, 513 (1921).
[2] C. Ramsauer, Ann. d. Physik **66**, 546 (1921).
[3] R. B. Brode, Phys. Rev. **25**, 636 (1925).
[4] E. Bruche, Ann. d. Physik **82**, 912 (1927).
[5] E. Bruche, Ann. d. Physik **83**, 1066 (1927).
[6] E. Bruche, Ann. d. Physik **84**, 279 (1927).
[7] R. B. Brode, Proc. Roy. Soc. **A125**, 134 (1929).
[8] R. B. Brode, Phys. Rev. **34**, 673 (1929).

four slits. The last slit of this system was 1 mm wide and 10 mm high. Electrons passing through this last slit entered a collector and were measured by a high sensitivity galvanometer placed between the collector and ground. The reading, I, of this galvanometer was taken as a measure of the intensity of the beam at the end of its path.

The initial intensity of the electron beam was taken as proportional to the total emission, M, from the slit in the cylinder which surrounded the filament. That this proportionality holds, even at low velocities, throughout the pressure range used is shown by the fact that the logarithm of the ratio of I to M is a linear function of the pressure. Fig. 1 shows several examples, taken in helium, of this linear relation. The consistency with which the points fall on a straight line is also an indication of the experimental accuracy of the determinations of the absorption coefficient at these low velocities.

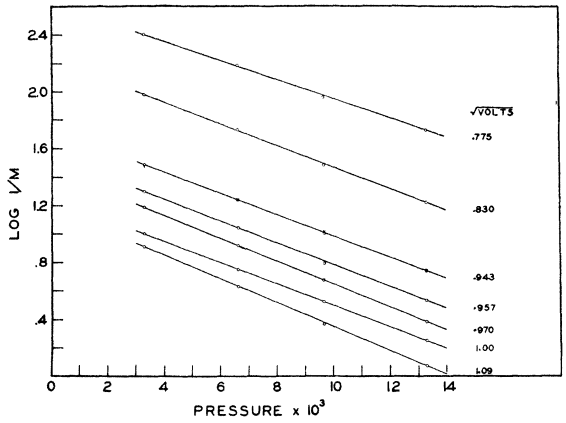

Fig. 1. Log of ratio of maximum current I at collector to total current M from slit in cylinder as a function of pressure, for low velocity beams in helium.

Due to the potential drop in the filament and the contact e.m.f. between the tantalum cylinder and the tungsten filament the applied potential will not give the true velocity of the electrons. The true velocity was determined from the magnetic field required to bend the electron beam into the circular path defined by the slit system of the apparatus. If r is the radius of this path, H the magnetic field strength in gauss, and V the energy of the electrons in equivalent volts, $H\ r = 3.3\ V^{\frac{1}{2}}$. Since r is a constant of the apparatus the electron velocity in root volts is proportional to the magnetic field strength or to the current, I_h, producing the magnetic field. Working with acceleration potentials of 100 volts or more, where the filament drop and the contact e.m.f. were negligible, the square root of the accelerating potential when plotted against I_h gave a straight line passing through the origin, Fig. 2. From the slope of this line the velocity corresponding to any value of I_h could be calculated. For accelerating potentials below 25 volts the influence of the filament drop and the contact e.m.f. becomes appreciable causing the points to lie above the straight line which gives the true velocity.

As a check of this method of velocity determination retarding potential curves were taken at a number of velocities between 0.5 and 1.2 volts. With a given accelerating potential I_h was varied until I was a maximum. From this value of I_h the velocity of the electrons was calculated. A retarding

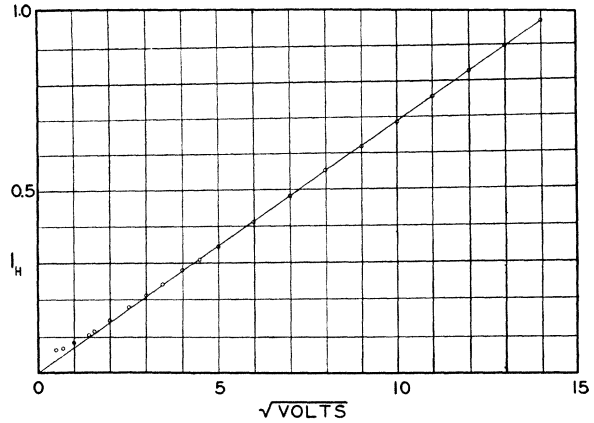

Fig. 2. Deflecting magnetic field current I_h as a function of the square root of the accelerating potential.

potential was then applied between the collector and ground and the values of I corresponding to measured increasing values of the retarding potential were recorded. The points of inflection of the curves obtained by plotting the collector current, I, against the retarding potential give the velocity of the electrons. Four of these curves are shown in Fig. 3. The vertical lines indicate the velocity as calculated from the deflecting magnetic field

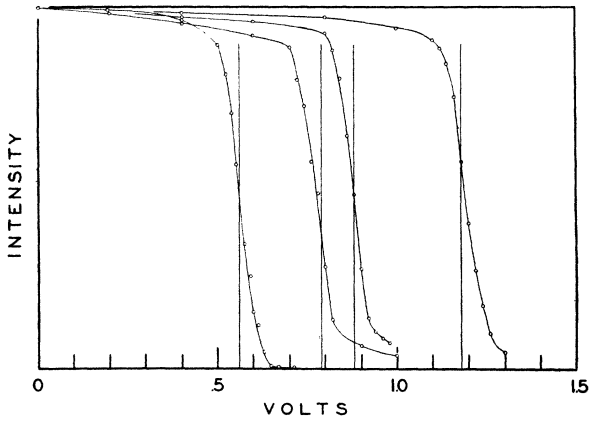

Fig. 3. Intensity of electron current arriving at collector as a function of retarding potential applied between collector and ground.

current I_h, Fig. 2. For six velocities between 0.5 and 1.2 volts the mean deviation of the values as measured by the two methods was 0.014 volts.

These retarding potential curves give also a measure of the velocity resolving power of the apparatus. The width of the half maximum of the

electron velocity distribution curves is found to be 0.035, 0.040, 0.031, 0.030 volts$^{\frac{1}{2}}$ for mean velocities equivalent to 0.56, 0.79, 0.88, 1.18 volts respectively. From the dimensions of the apparatus the maximum variation of the velocity of the electrons passing through the last slit should be about 3 percent of the mean velocity.

Results

The results are shown in Figs. 4 to 9 where the absorption coefficient, α, is plotted as a function of the electron velocity in volts$^{\frac{1}{2}}$. The previous results of Brode, and Bruche, are also given. All the observed values of α have been plotted in each case. The consistency of the results is shown by the fact that many of the points taken on different days agree within less than one percent. α is expressed in square centimeters per cubic centimeter of the gas at 0°C and a pressure of 1 mm of Hg.

Hydrogen was prepared by the electrolysis of barium hydroxide and was further purified and dried by passage over heated copper and through a phophorous pentoxide tube. The general form of the curve agrees well with the results of Bruche. A small secondary maximum in the curve appears at 2.2 volts$^{\frac{1}{2}}$, and at 1.55 volts$^{\frac{1}{2}}$ a sharp peak similar to those observed by Brode in the alkali metal vapors is superimposed on the broad maximum previously observed. A distinct minimum occurs at 1.1 volts$^{\frac{1}{2}}$ beyond which the curve rises rapidly with decreasing velocity.

Helium was purified by slow passage through a charcoal trap immersed in liquid air, the trap having been previously baked at 500°C. At the higher velocities the results are in good agreement with those of Brode. The maximum, however, occurs at a velocity lower than determined by Brode and Bruche and appears as two distinct and almost equal maxima. Beyond the second maximum is a minimum at 0.92 volts$^{\frac{1}{2}}$ and for still lower velocities the curve rises slightly.

Argon was purified by a magnesium arc. There are indications of fine structure between 4.5 and 5.5 volts$^{\frac{1}{2}}$. The minimum is at about 0.8 volts$^{\frac{1}{2}}$.

Neon, purchased as 99.5 percent pure, was used without further treatment. The value of α increases steadily to a maximum at about 5 volts$^{\frac{1}{2}}$. From here the curve drops irregularly to a final minimum at 0.85 volts$^{\frac{1}{2}}$.

Nitrogen was prepared by the decomposition of sodium azide on being heated. The curve has a small maximum at 12 volts$^{\frac{1}{2}}$, pronounced fine structure between 2 and 3 volts$^{\frac{1}{2}}$ and a very large and sharp maximum at 1.5 volts$^{\frac{1}{2}}$. A slight nick occurs at 1.2 volts$^{\frac{1}{2}}$ and a final minimum is reached at slightly below 1 volt.

Carbon monoxide was prepared by the decomposition of formic acid on being dropped into hot sulphuric acid, and was dried by passage through a phosphorous pentoxide tube. The results are in very good agreement with those of previous observers. The similarity between the CO and N_2 curves is seen to persist even in the fine structure.

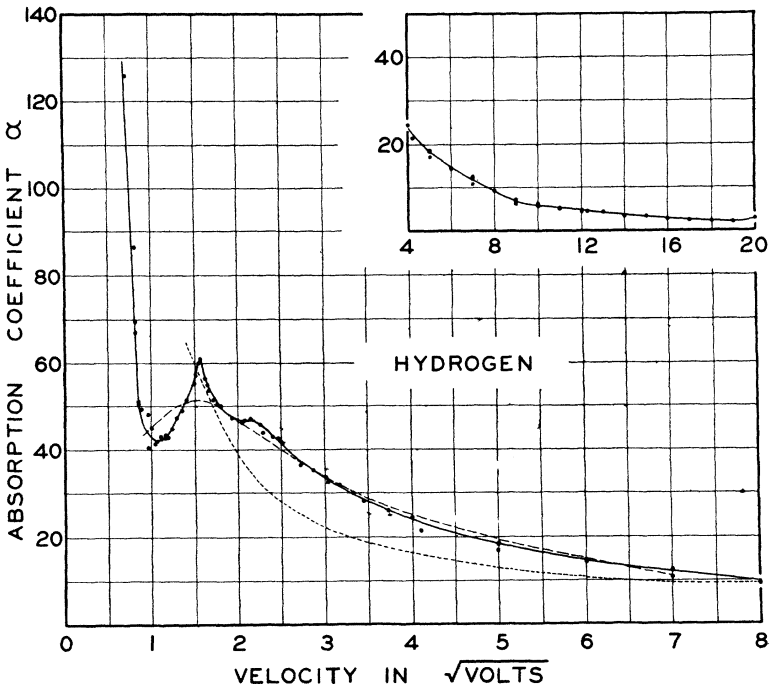

Fig. 4. The absorption coefficient α for electrons in hydrogen as a function of the velocity of the electrons.

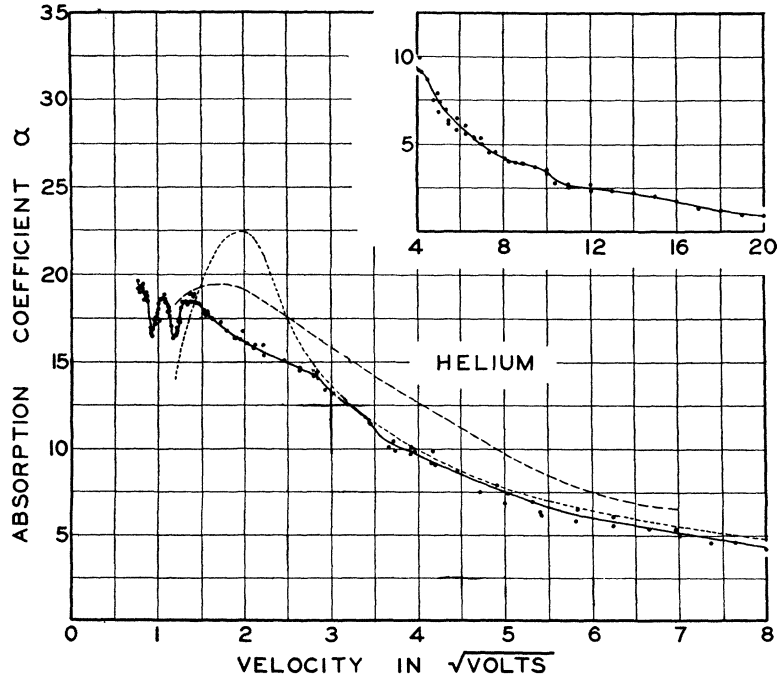

Fig. 5. The absorption coefficient α for electrons in helium as a function of the velocity of the electrons.

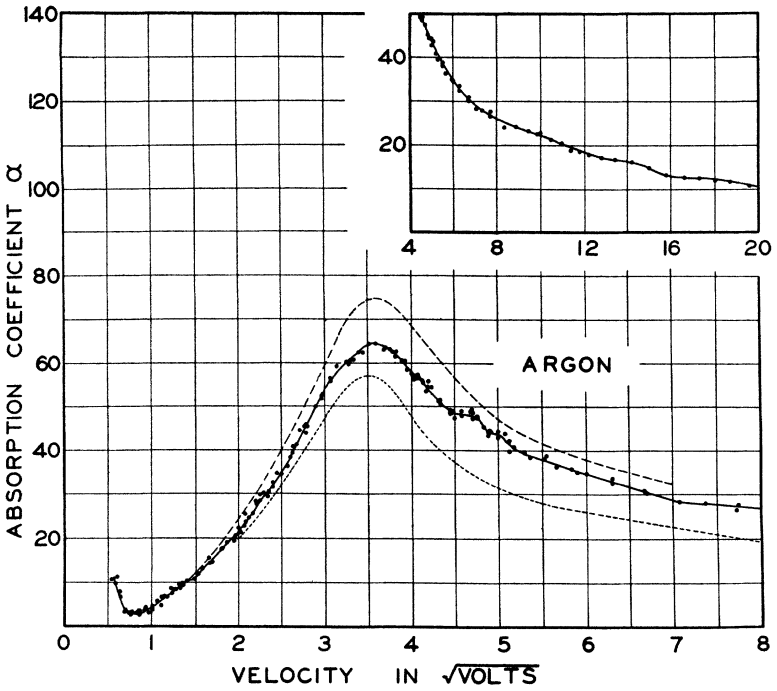

Fig. 6. The absorption coefficient α for electrons in argon as a function of the velocity of the electrons.

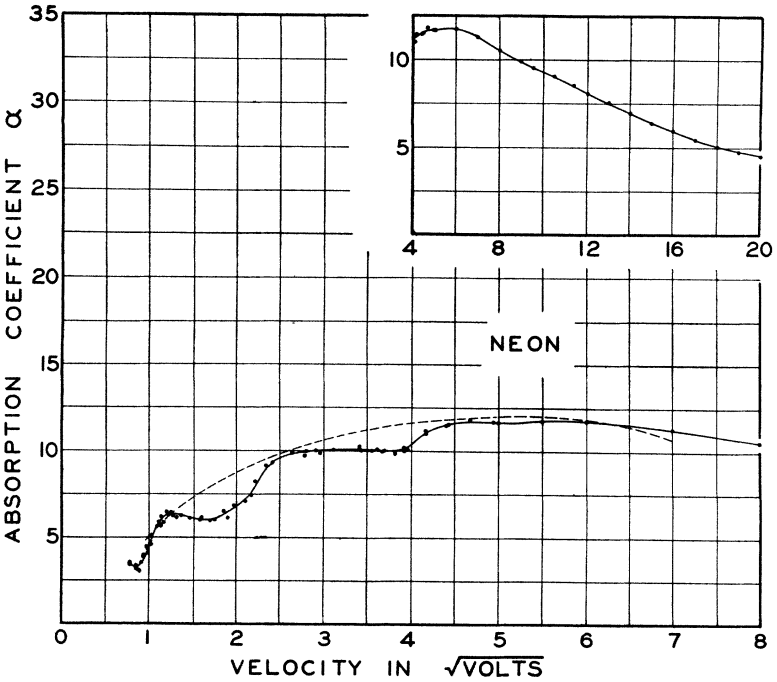

Fig. 7. The absorption coefficient α for electrons in neon as a function of the velocity of the electrons.

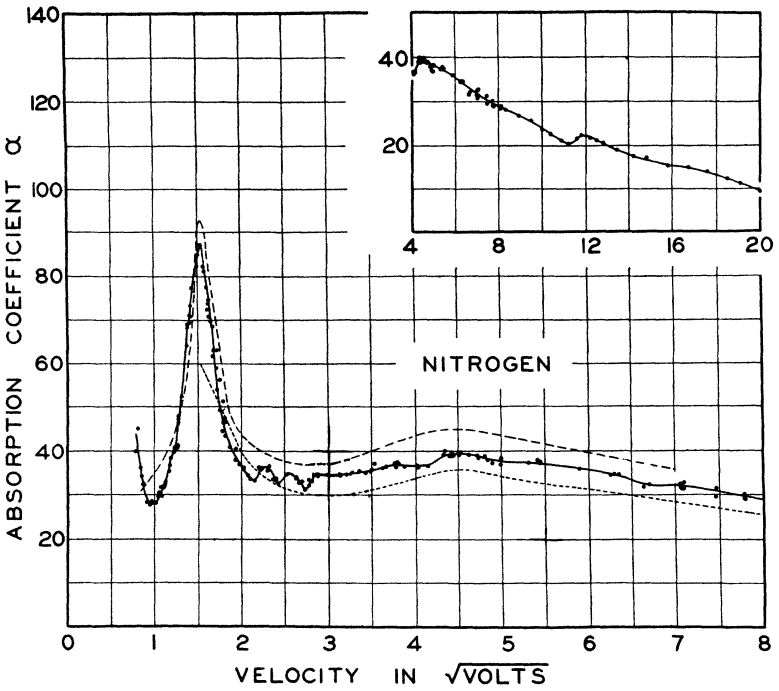

Fig. 8. The absorption coefficient α for electrons in nitrogen as a function of the velocity of the electrons.

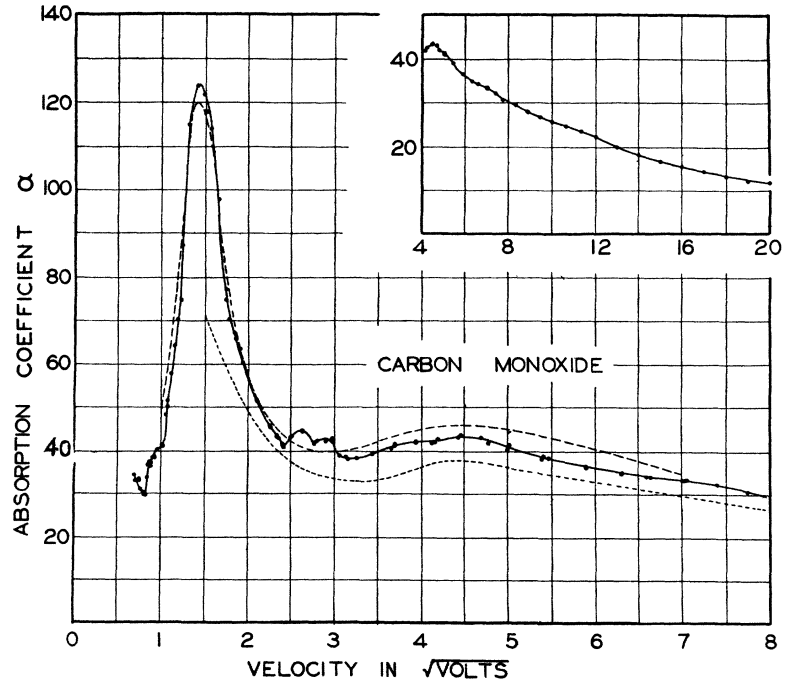

Fig. 9. The absorption coefficient α for electrons in carbon monoxide as a function of the velocity of the electrons.

Low Velocity Results

For velocities below 1 volt the intensity of the electron beam drops off very rapidly with decreasing velocity. Somewhat greater intensity and extended range toward lower velocity was obtained by applying an accelerating potential of about 1.5 to 2 volts and then retarding the electrons to the desired velocity. The values of α obtained with and without the auxiliary

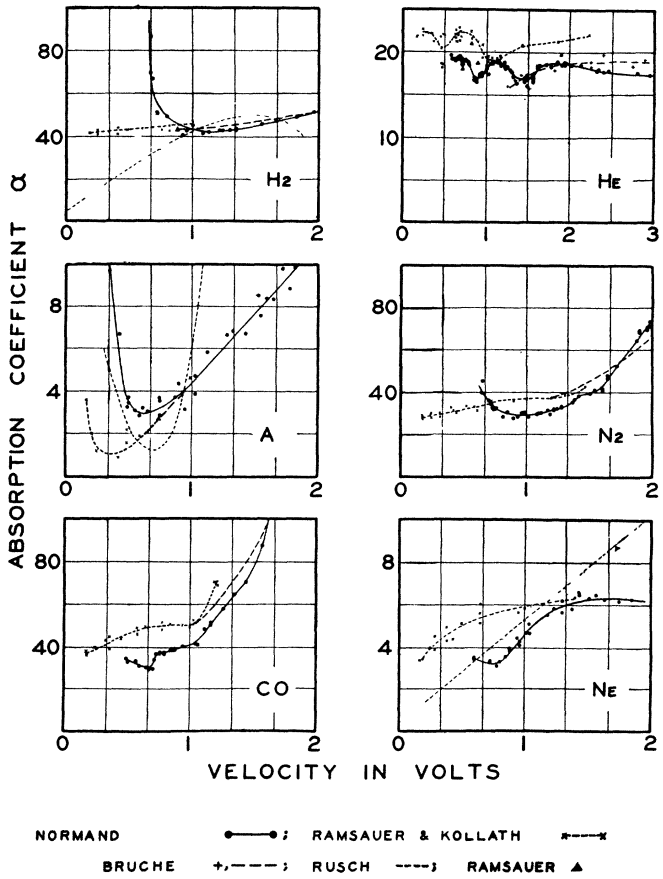

Fig. 10. The absorption coefficient α for very slow electrons in H_2, He, A, Ne, N_2, and Co as a function of the energy of the electrons in volts.

retarding potential were identical. The rapid diminution of intensity, however, rendered impossible the determination of α for velocities lower than about 0.5 volts except in the case of argon where measurements were extended to about 0.3 volts.

The results of these measurements for velocities below 2 volts, (3 volts in the case of He), are given in Fig. 10 together with the recent results of Ramsauer and Kollath,[9,10] the earlier results of Bruche,[11] and the points

[9] C. Ramsauer and R. Kollath, Ann. d. Physik **3**, 536 (1929).
[10] C. Ramsauer and R. Kollath, Ann. d. Physik **4**, 91 (1929).
[11] M. Rusch, Phys. Zeits. **26**, 748 (1925).

obtained by Ramsauer[1] in his first measurements. Here α is plotted as a function of the electron energy in equivalent volts rather than of electron velocity, volts$^{\frac{1}{2}}$. In no case is the agreement with Ramsauer and Kollath as good as might be expected from the accuracy of the measurements in each case.

A comparison of the results in the case of helium is especially interesting. The actual magnitude of the values of α given here are about 17 percent smaller than those given by Ramsauer and Kollath. Neglecting this difference in magnitude, which is of little importance, the two curves are seen to be nearly identical if Ramsauer and Kollath's velocities are increased by about 0.4 volts or if the velocities in this paper are decreased by the same amount. The agreement with the results obtained by other observers is seen to be better for the values of velocity given in this paper than for those given by Ramsauer and Kollath.

What has been said about the disagreement of the values of the velocity for helium is equally true for all the other gases measured. The magnitudes of the coefficient are in somewhat closer agreement but the volt scale is still displaced by about 0.4 to 0.6 volts. As already described, the velocity has been carefully checked throughout these measurements. Ramsauer and Kollath have also checked their velocities by both the retarding potential and the magnetic deflection method. The most probable source of the discrepency would appear to be a contact e.m.f. The thin sheet tantalum parts of the apparatus used in this experiment were spotwelded together. The apparatus was baked at 500°C for several hours and the tantalum parts were heated to a bright yellow with an induction furnace. At no time were unsteady conditions such as reported by Ramsauer and Kollath observed. The apparatus of Ramsauer and Kollath was constructed of brass and placed under an evacuated bell-jar. The unsteady conditions arising from contact e.m.f.s between the parts of the apparatus made necessary the complete dismanteling of the apparatus and the scraping of all metal surfaces at intervals of about 10 days. By this treatment steady and repeatable measurements were obtained with their apparatus.

The author wishes to express his indebtedness to Professor R. B. Brode for proposing this investigation, for his many helpful suggestions, and for his interest throughout the work.