Electron Loss Cross Sections for Helium Atoms Passing Through Gases

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Neutral helium atoms having kinetic energies in the range 100 to 450 kev are passed through a gas cell in which there is an intense magnetic field. When a few microns pressure of gas is admitted to the cell, an attenuation of the transmitted beam takes place, due to collisions in which the helium atoms become ionized, and removed from the unidirectional beam by the magnetic field. The method will not distinguish between collisions in which one or both helium electrons are lost. The sum of the cross sections for the two processes is measured, per atom of gas traversed. The cross sections rise in a rather uniform manner as energy increases in this range. In units of 10^{-17} cm^2 per atom of gas traversed, the values at 100 and at 450 kev are: for air, 30.2±0.8 and 43.9±1.5; for hydrogen, 5.8±0.6 and 12.5±0.8; and for helium, 11.6±0.6 and 16.8±0.4.

1. INTRODUCTION

THIS paper reports experiments which contribute to our knowledge of the charge changing collisions of helium ions passing through gaseous media. The kinetic energies of the ions lie in the range 100–450 kev, where their translational speeds are comparable to the speed of the electrons in the neutral helium atom. The experiment is one which measures the sum of the cross sections for producing magnetically deviable charged ions from moving neutral atoms. Using the notation of Snitzer,[1] where σ_{if} is the cross section for a collision in which the initial positive charge of the moving ion is i and its final charge f, in electron units, the present experiments measure the sum $(\sigma_{01}+\sigma_{02})$, referring to the processes $He^0 \rightarrow He^+ + \epsilon$ and $He^0 \rightarrow He^{++} + 2\epsilon$, respectively.

The experimental results on charge changing collisions in helium as of June, 1953, have been reviewed by Allison and Warshaw.[2] At that time the equilibrium fractions of the various charged states in a helium beam had been measured by Snitzer[1] in the present energy range, and certain scattered data were available on equilibrium ratios and cross sections σ_{12} at energies extending upward from 646 kev were available from Rutherford's work.[3] Since that time Bittner[4] has reported an application of these phenomena in the production of a He^{++} beam for the van de Graaff acceleration. This is accomplished by the preliminary acceleration of the readily available He^+ through 400 kev, followed by stripping to He^{++} by passing through a small amount of gas. Also a group at Oak Ridge[5] have measured the equilibrium charge distribution of helium ions in the range 20–250 kev passing through the gases H_2, He, N_2, O_2, Ne, and A. In the region between 100 and 200 kev, where there is some overlapping of their results with those of Snitzer, the Oak Ridge investigators find approximately 20 percent more He^0 in the equilibrated beam. The variation of the equilibrium fractions with respect to beam energy, and with atomic number of the gas traversed, is the same in both investigations. The equilibrium fraction $He^{++}/(He^{++}+He^{+}+He^{0})$, which varies from 0.02 to 0.04 in the region where the two researches overlap is essentially the same in both, subject to the rather large error in measuring such a small fraction.

Measurements of the charged fractions in the equilibrated beam do not of themselves give information concerning any single cross section, since only cross-section ratios are concerned. An experiment which gives a cross section directly must involve transient conditions, in which the thickness of the layer traversed is not sufficient to equilibrate the beam. Some cross sections σ_{10} for He^+ ions at energies below 40 kev have been obtained by Stedeford and Hasted.[6] Values of σ_{12} for He^+ ions in various gases at 10 and 20 kev have been reported by Fedorenko.[7] There do not seem to have been any loss cross sections for He^0 measured previously.

2. METHOD OF THE EXPERIMENT

The technique of the experiment is essentially the same as that of Montague[8] and Kanner[9] in their measurements of electron loss cross sections for hydrogen atoms in H_2 and in air. The beam of neutral helium atoms was obtained by allowing the He^+ beam from the University of Chicago's Cockcroft-Walton accelerator (kevatron) to pass through a small amount of gas, and then bending away the charged components, He^+ and He^{++}, from the emergent beam by means of a magnetic field.

The neutral beam then passed through a measuring chamber situated in the magnetic field, and was detected by a secondary electron emission detector at its far end. When gas at a known pressure, p, is admitted into the chamber, some of the neutral helium atoms collide with the gas molecules, are stripped of one, or

[1] E. Snitzer, Phys. Rev. **89**, 1237 (1953).
[2] S. K. Allison and S. D. Warshaw, Revs. Modern Phys. **25**, 779 (1953).
[3] E. Rutherford, Phil. Mag. **4**, 277 (1924).
[4] J. Bittner, Rev. Sci. Instr. **25**, 1058 (1954).
[5] Stier, Barnett, and Evans, Phys. Rev. **96**, 973 (1954).
[6] J. B. H. Stedeford and J. B. Hasted, Proc. Roy. Soc. (London) **A227**, 466 (1955).
[7] N. V. Fedorenko, Zhur. Tekh. Fiz. **24**, 769 (1954).
[8] J. H. Montague, Phys. Rev. **81**, 1026 (1951).
[9] H. Kanner, Phys. Rev. **84**, 1211 (1951).

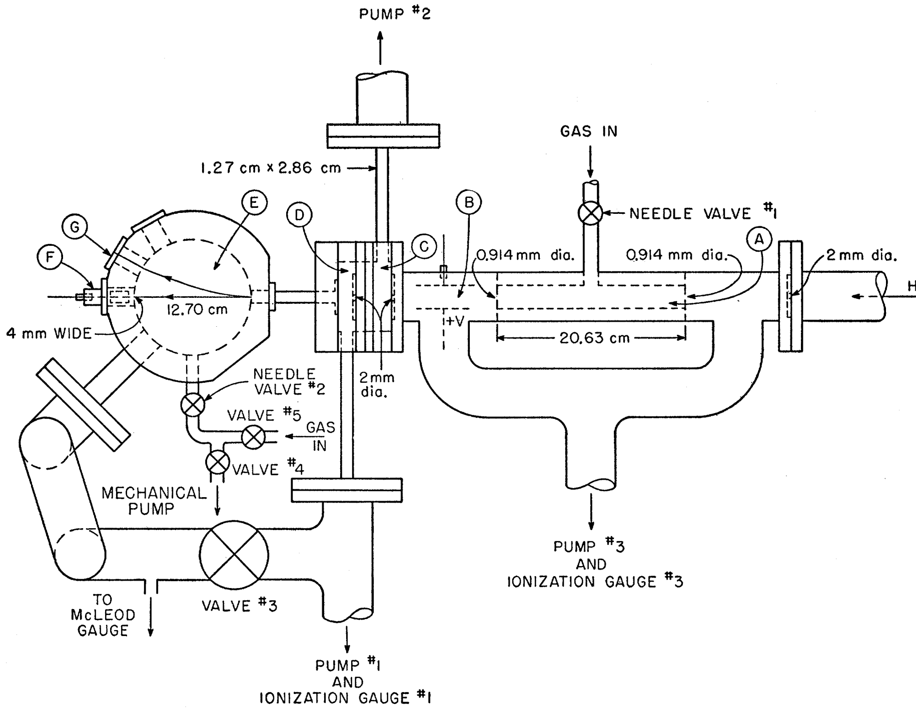


FIG. 1. Apparatus. Neutral helium is produced by charge equilibration of a He^+ beam in the differentially pumped gas cell A. Loss cross sections are measured in chamber E, in the presence of a magnetic field perpendicular to the plane of the figure.

perhaps two electrons, and then are removed from the beam by the magnetic field, thus giving rise to an attenuation of the neutral beam.

The electron loss cross section per atom of gas traversed is given by

$$(\sigma_{01}+\sigma_{02})=\frac{kT}{pl\xi}\ln\frac{R(0)}{R(p)}, \tag{1}$$

where l is the path length in the measuring chamber, $R(0)$ is the normalized beam intensity with no gas in the chamber, and $R(p)$ that when the gas pressure in the chamber is p dynes/cm^2. k is the Boltzmann constant, T the temperature in °K, and ξ is the number of atoms per molecule in the gas.

3. DESCRIPTION OF THE APPARATUS

A schematic diagram of the apparatus is given in Fig. 1 and will be referred to in the following discussion.

A. Equilibrating Cell

This is cell A of Fig. 1. In it, the beam of He^+ ions is charge equilibrated by passing through a gas. The cell is a pipe 20.63 cm long having small holes, 0.94-mm diameter, at both ends. Diffusion pumps 1, 2, and 3 and the kevatron diffusion pumps have sufficient pumping speed so that when a controlled amount of gas is admitted through needle valve No. 1 no perceptible rise in pressure occurs in the kevatron or the measuring chamber E. Sufficient gas is admitted to establish charge equilibrium, and this can be accomplished without significantly decreasing the average energy of the transmitted beam.

The pressure used in the equilibrating cell was on the order of 10 microns. If one calculates the energy lost by 400-kev helium ions in air, using an energy loss cross section[10] of 84.6×10^{-15} ev$\times$cm^2/molecule, one finds the energy loss is less than one kev. For lower energies, or for lighter gases in the equilibrating cell, the loss would be less.

B. Beam Monitor

The emergent beam, now about 1-mm diameter, next passes through the monitor (B in Fig. 1), which is essentially a parallel plate ionization chamber. The lower plate is connected through an insulated seal to the positive terminal of a 90-volt battery; thence to ground. The upper plate is connected through a well-insulated (10^{13} ohms) Teflon seal to some type of current integrator. With enough gas in the equilibrating cell to establish charge equilibrium, the gas pressure in the monitor region was sufficient to give currents of the order 10^{-10} ampere.

C. Differential Pumping System

Since the monitor current is directly proportional to the gas pressure between the two plates it is essential that the pressure here remain unchanged when gas is admitted to the measuring chamber E. In order to accomplish this it was necessary to install two stages of differential pumping, represented in Fig. 1 by cham-

[10] P. K. Weyl, Phys. Rev. 91, 289 (1953).

bers C and D and diffusion pumps 1 and 2. Evidence that no gas was backing up into the monitor region was obtained by noting no increase in the reading on ionization gauge 3 when the pressure in E was increased from 10^{-4} mm Hg to 10^{-2} mm; the latter being the highest pressure used in these measurements. Furthermore, with a steady beam passing through the system no increase in monitor current was observed when the pressure in E was increased.

D. Measuring Chamber and Detector

After leaving the differential pumping chambers, the beam passed through a steel plug with a 2-mm diameter hole, and then into the measuring chamber. This hole had to be big enough to pass the entire equilibrated helium beam, and yet small enough to permit the required pressure differential between E and B.

The measuring chamber[11] is a hollow bronze cylinder designed to fit snugly between the pole faces of the electromagnet. Diametrically opposite to the 2-mm entrance hole is a port into which is inserted the neutral particle detector (F in Fig. 1). There is also a port, G, whose axis is directed to the center of the circle and at an angle of 30° to the axis of the detector. At this "thirty-degree" port was placed a glass plate, covered on the inside with ZnS powder. As will be shown later, the effective path length for attenuation depends on the radius of curvature of the ions in the magnetic field. This radius of curvature was maintained constant at all beam energies by adjusting the magnetic field so that the spot from the He^+ portion of the equilibrated beam could always be seen at a fixed point on the ZnS surface.

The detector is the same as that used by Montague.[8] It consists of an inclined beryllium-copper plate in the path of the beam and a grounded electrode parallel to the collecting plate but out of the way of the beam. A saturating negative potential (-67.5 volts) is applied to the collecting plate so that when a neutral atom strikes it, the secondary electrons are driven to the grounded plate. The geometry is such that the electron paths are parallel to the magnetic lines of force. The net positive current to the collecting plate was summed on a small current integrator.

E. Current Integrators

Three different circuits were used as current integrators in the course of these measurements, and every cross section reported here was measured with two or more different combinations of them. In each of the three circuits, the rise of voltage across a high-quality condenser was detected as the condenser was being charged by the current to be measured. This rise in voltage was detected by (1) a quadrant electrometer,[12] (2) a battery-operated dc amplifier of standard design,[13] and (3) a vibrating reed electrometer.[14]

F. Pressure Measurements

For a quick-acting pressure indicator, useful in setting the needle valve, pressures could be read on an Alphatron[15] gauge. All pressures used in calculating cross section, however, were measured on a liquid nitrogen trapped McLeod gauge. At first it was difficult to obtain reliable McLeod readings because of the tendency of the mercury to stick in the capillaries. This difficulty was completely overcome by roughening the inner surfaces of both capillaries with carborundum in the manner suggested by Rosenberg.[16] After this roughening, the diameter of the capillary was measured by introducing weighed amounts of mercury. The calibration of the gauge was also checked by stopping the mercury columns at different points with the same trapped gas. Pressures computed from these measurements always agreed to within 3 percent.

G. Gases

The only precaution taken in admitting air for attenuation measurements was to pass it through a calcium chloride drying tube. There were occasional indications that the gases H_2 and He were contaminated by heavier gases when in the measuring chamber. They were brought to needle valve No. 2 from their storage tanks through short plastic tubing lines in which the gases were kept slightly above atmospheric pressure and constantly flowing. Electrolytic hydrogen was used, with a "Deoxo"[17] catalytic unit to combine the oxygen, followed by a trap immersed in liquid nitrogen to freeze out the water vapor. The helium used was government grade A, 99.9 percent pure.

4. EXPERIMENTAL PROCEDURE

A. Measurement of Attenuation Ratio and Pressure

The procedure in a typical cross-section measurement will be described with reference to Fig. 1. Gas was first admitted through needle valve No. 1 into the equilibrating cell; then with the beam directed so as to pass through the apertures of this cell, the magnetic field on the measuring chamber was adjusted until the He^+ spot appeared at the 30° port.

Then the quantities $R(0)$ and $R(p)$ of Eq. (1) were determined by taking readings of the quantity of charge collected by the detector in the time that the monitor collected a fixed amount of charge, first with

[11] Described more fully in reference 8.
[12] Described in U. S. Atomic Energy Commission Document MDDC-562 (unpublished).
[13] The circuit ("Zeus") is given on the data sheet for the Raytheon CK5697/CK570 electrometer triode.
[14] Built by the Applied Physics Corporation, Pasadena, California.
[15] National Research Corporation, Cambridge, Massachusetts.
[16] P. Rosenberg, Rev. Sci. Instr. 9, 258 (1938).
[17] Baker and Company, Newark, New Jersey.

vacuum in the measuring chamber, and then after gas was admitted. The pressure was then taken. By closing valve 5 and opening valve 4, vacuum could be produced in the measuring chamber without mechanically closing the needle valve No. 2, thus preserving its setting for subsequent gas in, gas out cycles.

Data from a typical experiment are exhibited in Fig. 2. Referring to this figure, if we let $p_{\frac{1}{2}}$ represent the pressure at which the attenuation ratio would be 0.5, as read by extrapolation from the plot, Eq. (1) becomes

$$(\sigma_{01}+\sigma_{02})=0.693(kT)/l\xi p_{\frac{1}{2}}.$$

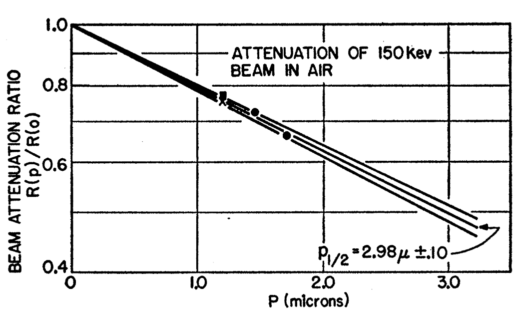
Using $l=10.11$ cm, $T=287$°K, $k=1.38\times10^{-16}$ erg/°K, $\xi=2$, and $p_{\frac{1}{2}}=(2.98\pm0.10\mu)(1.33)$ dynes/(cm^2 μ), we obtain

$$(\sigma_{01}+\sigma_{02})=(34.1\pm1.1)\times10^{-17}\text{ cm}^2\text{ per air atom.}$$

B. Determination of Attenuation Path Length

The effective path length is less than the diameter of the measuring chamber because ions formed close to the detector do not have their paths deviated sufficiently by the magnetic field to miss the entrance slit to the detector. It is clear that this "ineffective distance" z is determined by the radius of curvature of the He^+ ions in the magnetic field, the width and shape of the beam, and the location of the undeflected, neutral beam in the detector slit opening. As pointed out before, the radius of curvature for He^+ was kept the same (23.7 cm) in all experiments.

The width and location of the beam were measured as follows. A simple circuit was devised by means of which the current through the magnet could be varied continuously from −0.25 to 0.25 ampere, sufficient to sweep the charged component of the beam completely across the slit. The measuring chamber was evacuated; and for each magnet current setting the normalized beam intensity, $R(0)$, and the magnetic field strength were measured. The latter was accomplished with a rotating coil fluxmeter driven by a synchronous motor. The resultant plot of $R(0)$ *versus* fluxmeter reading is shown in Fig. 3.



INTEGRATED DETECTOR CURRENT READ BY:	INTEGRATED MONITOR CURRENT READ BY:
x- QUADRANT ELECT.	DC AMPLIFIER AND GALV.
■- DC AMPLIFIER AND GALV.	QUADRANT ELECT.
●- VIBRATING REED ELECT.	QUADRANT ELECT.

FIG. 2. Typical experimental data. $R(p)/R(0)$ is the ratio of the monitored emergent beam intensity with gas in the cell to its value with the cell evacuated.

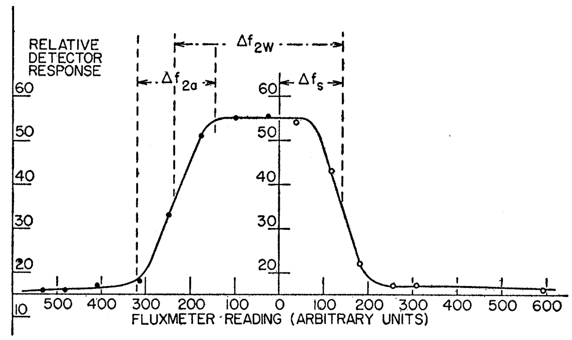


FIG. 3. Response of the detector as the charged component of the beam is swept across the detector aperture by varying the magnetic field. The asymmetry about $H=0$ shows that the neutral beam does not fall exactly in the center of the slit. When cross-section measurements were being made, the charged beam was deflected to the right.

From an inspection of Fig. 4, it is seen that a small linear displacement d of the charged component of the beam, caused by the magnetic field, is given by

$$d=D^2/2\rho, \quad (2)$$

where ρ is the radius of curvature of He^+ in the magnetic field, and $D=12.70$ cm is the distance from the entrance of the measuring chamber to the detector slit. Since $H\rho$ is constant for a given ion momentum and charge, d is proportional to H and thus to the fluxmeter reading.

Using this proportionality, we may make certain useful calculations. First, we note that the change of fluxmeter reading Δf_{2W} (Fig. 3) corresponds to a displacement of the center of the beam through the known width of the detector slit ($2W=4$ mm). The fluxmeter change Δf_{2a} corresponds to a displacement of the center of the beam a distance equal to the beam diameter $2a$. Thus

$$2a=(\Delta f_{2a}/\Delta f_{2W})(2W)=1.88\text{ mm.} \quad (3)$$

Furthermore, Δf_s represents the distance from the center of the undeflected beam to the closest edge of the slit, and this distance s is

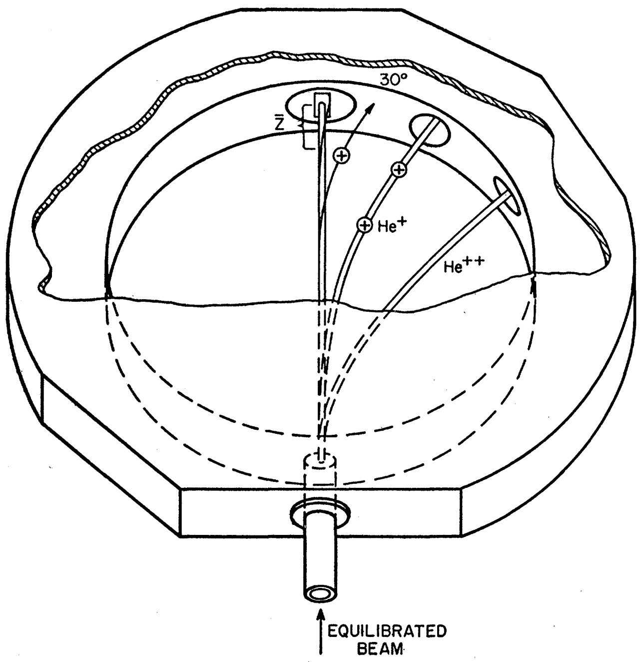
$$s=(\Delta f_s/\Delta f_{2W})(2W)=1.51\pm0.2\text{ mm.} \quad (4)$$

Now, to calculate the effective path length, we assume the beam to have a circular cross section of radius $a=0.94$ mm, and average the "ineffective distance" z over the cross section of the beam. One arrives at the formula,

$$\bar{z}=(2\rho)^{\frac{1}{2}}\int_{-a}^{a}[(s-x)(a^2-x^2)]^{\frac{1}{2}}dx\bigg/\int_{-a}^{a}(a^2-x^2)^{\frac{1}{2}}dx, \quad (5)$$

for the average ineffective distance.

Numerical integration of the above formula with $\rho=23.7$ cm gives $\bar{z}=2.59$ cm, so for the effective path



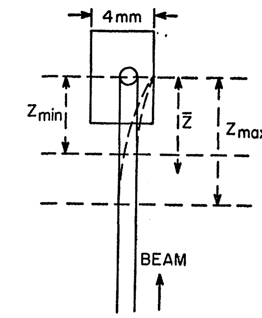


FIG. 4. If a singly charged helium ion is produced from a neutral in the region $\bar{z}$, the magnetic deviation is not sufficient to remove it from the detector aperture.

length for attenuation we have

$$l = D - \bar{z} = 10.11 \text{ cm}.$$

The path length l was also determined by another independent, but less accurate method. The electron loss cross section for 100-kev He atoms in air was measured in the standard magnetic field ($\rho = 23.70$ cm) and also in a larger magnetic field which corresponded to a radius of curvature of 11.2 cm for the He^+ ions. From Eq. (5), we see that $\bar{z}$ varies as $\rho^{\frac{1}{2}}$, so that the two attenuation lengths are $[D - \bar{z}]$ and $[D - \bar{z}((11.2)/(23.70))^{\frac{1}{2}}]$, respectively. Each of these lengths is proportional to the logarithm of the corresponding attenuation ratio, and from the observed ratio of these logarithms at constant pressure it resulted that $\bar{z} = 2.80$. In computing cross sections, however, the value $\bar{z} = 2.59$ was used.

C. Checks for Internal Consistency

(1). *Starting Point for Electron Loss Path*

The effective path length could conceivably be increased because of collisions with gas atoms located between the equilibrating cell and the measuring chamber if the fringing magnetic field were sufficiently strong in this region to separate out the charged ions. This source of error was shown to be negligible by the following experiment, in which the magnetic field was present.

With a certain gas pressure p present in the measuring chamber, the intensity of the attenuated He^0 beam was measured. Then the large valve 3 was opened, and the pressure p re-established in the measuring chamber by considerably increasing the opening of the needle valve No. 2. This greatly increased the gas pressure in chamber D, where the stray magnetic field might operate, but no measurable decrease in beam intensity resulted.

(2) *Saturation oj Bias Potential on the Detector*

With chamber E evacuated and the magnetic field on, it was found that $R(0)$ was independent of the bias voltage applied to the collecting plate of the Montague detector if such voltage was more negative than -45 volts. The bias used was -67.5 volts, and since the maximum potentials built up on the detector in the course of measurement were of the order of one volt, saturation was maintained.

(3) *Saturation of Bias Potential on the Monitor*

By measuring $R(0)$ as a function of monitor plate potential, saturation in the collected ion current was found if the drop across the monitor plates exceeded 65 volts; 90 volts was used in the experiments.

(4) *Gas Effect on the Detector*

Montague[8] and subsequent investigators who used this detector for hydrogen charge exchange cross-section measurements found a small increase of detector sensitivity with gas pressure, but for the smaller gas pressures used in the present work, the effect was negligible. The evidence for this is that with the magnetic field turned off, there was no attenuation in the neutral beam when gas was admitted to the measuring chamber.

(5) *Effect of Small-Angle Rutherford Scattering*

The absence of beam attenuation when gas is admitted, but with no magnetic field, shows that the spreading of the beam by small-angle Rutherford scattering has not diverted an appreciable amount of it outside the aperture of the detector. This is because the beam diameter (1.88 mm) at the detector slit is considerably less than the width and height of the slit (4×4 mm). The absence of an effect was confirmed by a calculation of the scattering to be expected.

5. RESULTS

The results are listed in Table I and plotted in Fig. 5. The errors listed are estimates based on the scatter of the points about the chosen straight lines in the plots of the logarithm of the attenuation against the pressure (see Fig. 2). They do not include possible systematic errors.

Table I also includes values of a parameter γ_i which has the following significance. Suppose the electrons in the complete atom corresponding to the moving ion are numbered serially, 1, 2, $\cdots i$, $\cdots Z$, in order of increasing binding. Suppose that at some point in the path of the moving ion the ith electron is the outermost one, all the electrons of lesser binding having been lost. Let I_i be the ionization potential which will remove this ith electron from the ion. Then we define a velocity,

$$V_i = (2I_i/m)^{\frac{1}{2}}, \tag{6}$$

to be referred to as the orbital velocity of the outermost electron adhering to the ion. m is the electron mass. If V is the translational velocity of the moving ion,

$$\gamma_i = V_i/V. \tag{7}$$

For the moving neutral helium atom, γ_1 refers to either of the two $1s$ electrons. In this somewhat special case, I_1 is clearly to be interpreted as one-half of the sum of the first and second ionization potentials of helium; $I_1 = \frac{1}{2}(54.1+24.5)$ or 39.3 ev, whence $V_1 = 3.73\times 10^8$ cm/sec.

It was found by repeating measurements in air that these cross sections were always reproducible within <7 percent. Unfortunately, this was not true for the other two gases, H_2 and He. It is perhaps significant that the lower values of cross sections obtained for these gases were the more self-consistent, as if, in spite of all precautions, there was occasional contamination with air or heavier gases.

TABLE I. Experimental results. Sum of the cross sections for the loss of one or both electrons from a moving helium atom.

Kinetic energy of He^0 in kev	V cm/sec $\times 10^8$	γ_1 [see Eq. (7)]	$(\sigma_{01}+\sigma_{02})\times 10^{17}$ square centimeters per atom H_2	He	Air
100	2.20	1.69	5.8±0.6	11.6±0.6	30.2±0.8
120	2.41	1.55	7.8±0.6	···	···
150	2.70	1.38	8.4±0.5	12.6±0.7	34.1±1.1
200	3.12	1.20	9.2±0.4	13.6±0.7	···
250	3.48	1.07	10.3±0.7	13.6±0.7	38.2±1.0
300	3.82	0.98	11.4±0.7	···	···
350	4.12	0.90	···	14.9±0.9	44.6±1.0
400	4.41	0.85	12.7±1.0	16.0±1.5	43.3±1.5
450	4.67	0.80	12.5±0.8	16.8±0.4	43.9±1.5

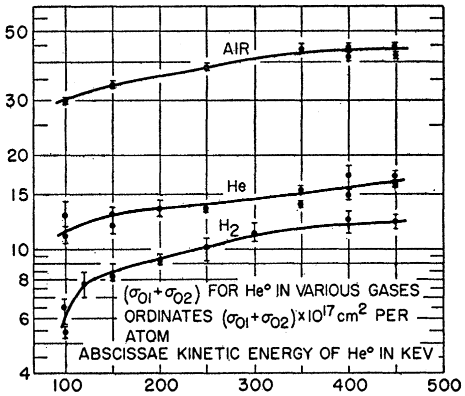


FIG. 5. Experimental values of the cross-section sum $(\sigma_{01}+\sigma_{02})$ in units of 10^{-17} cm² per atom of gas traversed, plotted against translational helium atom energy in kev.

Any error in the path length for attenuation would not affect the relative values of the cross sections since all measurements were made with the same path length. The agreement of the two different methods of measuring this length suggests that the uncertainty in l is less than 5 percent.

6. DISCUSSION

It is of interest to compare the loss cross sections reported here with those measured previously in this laboratory for hydrogen atoms in the kinetic energy range 30 to 325 kev.[8,9] These hydrogen measurements gave the cross sections σ_{01} for hydrogen atoms moving in the gases H_2 and air. The differences are both quanti-

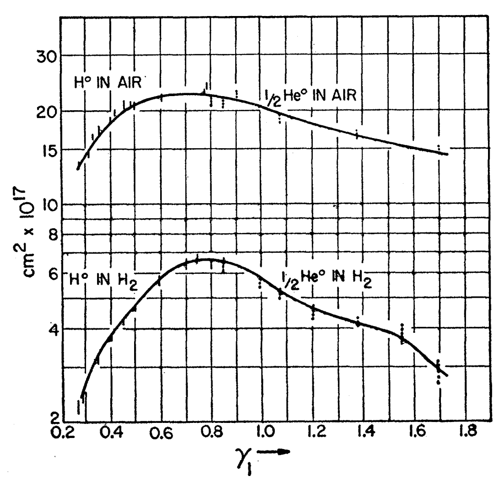


FIG. 6. Comparison of the electron loss cross sections for hydrogen atoms in air with one-half the electron loss cross sections of helium atoms in air. The lower curve shows the same comparison for hydrogen gas. Abscissas are values of γ_1, which is the ratio of the orbital speed of the outermost electron in the moving ion to its translational speed.

tative and qualitative. The loss cross sections for helium atoms are larger for the same gas and kinetic energy, and furthermore, within the energy range studied, the hydrogen loss cross sections are decreasing (they are roughly proportional to the energy to the power -0.70), but the helium cross sections are increasing.

If the cross sections per equivalent removable electron are plotted against the γ_1 values, however, there are indications that the phenomena show some regularity. Such a plot is shown in Fig. 6. The values of γ_1 for helium atoms have been given in Table I. The values of γ_1 for hydrogen atoms in Fig. 6 have been calculated from

$$\gamma_1 = 2.18\times 10^8/V, \tag{8}$$

where the numerator is the speed of the electron in the first Bohr orbit of the hydrogen atom, whose translational speed is V. In constructing Fig. 6, the measured helium cross sections have been divided by two, since the neutral helium atom has two identical electrons available for removal. It is seen that the loss cross section per equivalent removable electron seems to be a function of gamma only, with a maximum in the neighborhood of $\gamma_1 = 0.7$. It is very unfortunate that in the energy ranges through which the kevatron is operable the gamma ranges for H^0 and He^0 do not overlap, which prevents an extended test of the suggested simplification.

The rapid decline in the He^0 loss cross section in hydrogen gas as the helium kinetic energies fall below about 150 kev may be due to the approach to the threshold for transfer of the ionization energy from the protons in the hydrogen gas to the helium electrons, and to the increasing efficiency of the screening of the proton charge by the hydrogen electron during the collision. The critical speed for the transfer of 24.5 ev from a moving proton to an electron at rest is 1.47×10^8 cm/sec, which is the translational speed of a 44.5-kev helium atom. The velocities of the electrons in the helium atom will lower and decrease the abruptness of this threshold, but certainly a decrease of cross section in this region is to be expected.

7. ACKNOWLEDGMENTS

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