Electron Loss Cross Sections for Helium Atoms in the Kinetic Energy Range 100–450 kev*

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New measurements of the electron loss cross section for helium atoms in the kinetic energy range 100–450 kev are reported. It has been suggested that previous discrepancies between observers have been partially due to the fact that the neutral beams used contained varying amounts of metastable $1s2s\ ^3S_1$ atoms, depending on the pressure of the gas in which the He^0 beam was formed by electron capture from He^+. It is established that the new measurements were made on helium atomic beams whose loss cross sections were independent of the pressure at which they were prepared over a 10-fold variation. The new values show the same trend with kinetic energy and the same relative values in H_2, He, and air as those previously reported in the 100-450 kev range, but their absolute values are lower. The new values agree with those obtained in other laboratories in the range 100–200 kev. The results are shown in the following table, in units of 10^{-17} cm^2 per atom of gas traversed:

Kinetic energy (kev)	H_2	$(\sigma_{01}+\sigma_{02})$ He	Air
100	4.2	7.5	16.4
150	5.8	8.9	21.2
250	5.7	9.7	23.2
350	6.0	8.4	22.0
450	7.0	8.2	24.5

INTRODUCTION

SEVERAL papers have now reported electron loss cross sections of helium atomic beams prepared by allowing He^+ beams from an ion accelerator to neutralize themselves by electron capture in a gas film.[1,2] It has been suggested[1] that a complicating factor in such experiments may be that the electrically neutral helium beam, thus prepared, contains an unknown fraction of helium atoms in the metastable excited state $1s2s\ ^3S_1$. The electron loss cross section from such a state would presumably be larger than that from a $1s^2\ ^1S_0$ normal helium atom, and might explain the fact that the previously reported data show discrepancies by factors ranging from 1.7 to 2, cross sections measured by Krasner invariably being the larger.

In support of this suggestion, Barnett and Stier have found that for relatively low gas pressures (2–8 microns) of hydrogen in the charge-changing chamber, the apparent electron loss cross sections of emergent He^0 and Ne^0 beams are higher than at higher pressures in the charge changer. Such an effect was absent in non-noble gas beams of H^0 and N^0 thus produced, the loss cross sections remaining constant as the pressure was raised from 2 to 35 microns. The experiments reported in the present paper were undertaken in the attempt to find out if Krasner's measurements were influenced by this effect, and to repeat his measurements with the benefit of the technical experience gained since they were first performed.

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[1] C. F. Barnett and P. M. Stier, Bull. Am. Phys. Soc. Ser. II, 7, 41 (1955); Phys. Rev. **109**, 385 (1958).
[2] S. Krasner, Phys. Rev. **99**, 520 (1955).

APPARATUS AND METHOD

The total loss cross section $(\sigma_{01}+\sigma_{02})$ of the neutral helium beam was observed by passing it through a chamber in a strong magnetic field, so that any charged ions formed by electron loss[3] were removed. The resultant attenuation at a known gas pressure in the chamber gives the cross section from the expression

$$(\sigma_{01}+\sigma_{02})=(kT/pl\xi)\ln(I_0/I), \qquad (1)$$

where l is the path length in the magnetic field, p is in dynes/cm^2, k is the Boltzmann constant, and T is the absolute temperature. I_0 and I are the original $(p=0)$ and the pressure-attenuated beam intensities, and ξ, the number of atoms per molecule in the gas, is introduced so that the cross sections are measured per atom of gas traversed.

The essential parts of the apparatus are schematically indicated in Fig. 1. The inner cell in which the charge of the He^+ beam is changed and from which the emergent He^0 beam is selected is 20.63 cm long and has beam entrance and exit channels S_2, S_3 which are 0.091 cm in diameter and 0.159 cm long. The channels

[3] Strictly speaking, the total cross section measured here is $(\sigma_{01}+\sigma_{02}+\sigma_{0\bar{1}})$. He^- has been observed as a constituent of the emergent beam when a primary beam of He^+ ions, in the kinetic energy range 17–140 kev, is passed through a collision chamber. See Dukel'skii, Afrosimov, and Fedorenko, Zhur. Eksptl. i Teort. Fiz. **30**, 792 (1956); [translation: Soviet Phys. JETP **3**, 764 (1956)]. Also Windham, Joseph, and Weinman, Phys. Rev. **109**, 1182 (1958). Only rough estimates of the fraction of the He^+ beam transformed to He^- are available; they indicate yields of less than 0.001. The cross section $\sigma_{0\bar{1}}$ for moving helium atoms may be expected to be much less, at the same velocity, than $\sigma_{0\bar{1}}$ for moving hydrogen atoms. According to P. M. Stier and C. F. Barnett [Phys. Rev. **103**, 896 (1956)], $\sigma_{0\bar{1}}$ for 2.2×10^8-cm/sec hydrogen atoms (100 kev for helium atoms) is 8×10^{-18} cm^2 per target hydrogen atom.

S_1, S_4, and S_5, defining differential pumping compartments, were 0.226, 0.226, and 0.199 cm in diameter, respectively. S_1 and S_4 were 0.159 cm long; the length of S_5 was 0.317 cm.

A new feature in the present experiments is the movable slit S_6, a rectangular aperture in a thin metal strip. This opening is 0.198 cm in the plane perpendicular to the lines of force of the magnetic field and 0.5 cm parallel to them. The plane of the slit was 12.2 cm from the slit S_5 and this distance was used as the l of Eq. (1). The slit could be moved across the He^0 beam, thus obtaining its profile, and the background under it, by direct measurement. A disadvantage of the previous work[2] was that the correction for background had to be estimated by calculation, since the He^0 beam could not be moved aside by the magnet to reveal the background under it. In the previous work the calculated background effect (due to ions which had changed charge but which had not been swept out of the collecting aperture by the field) was quite a large correction and raised the cross sections, estimated from the observed attenuation ratios and the measured path length in the magnetic field, by 26%.

A second improvement was the use of a fine mesh screen electrode, described elsewhere,[4] to intercept the beam at M (Fig. 1) and collect a fraction of the beam current for monitoring purposes. This has proved more reliable than the ionization-chamber monitor previously used.

Due to the interest in the possibility that different pressures in the charge-changing cell might produce neutral helium beams of different loss cross sections, provision was made for measuring the charge-changing cell pressure with a McLeod gauge which could measure pressures as low as 5×10^{-6} mm Hg. In the previous experiment only estimates of this pressure from thermocouple gauge measurements were made.

The following tests were carried out:

(a) Admission of gas into the measuring chamber produced no attenuation of the mixed beam in the absence of the magnetic field.

(b) The attenuation of the He^0 beam was independent of the magnetic field strength over a wide region which included the strength at which measurements were made.

(c) Admission of gas into the measuring chamber did not affect the reading of the screen monitor M.

(d) The ratio I_0/I_p was a simple exponential function of the pressure from $I_0/I_p=1.2$ to 2 [Eq. (1)].

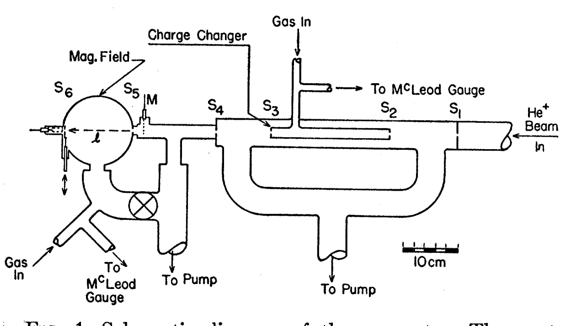

FIG. 1. Schematic diagram of the apparatus. The neutral beam was detected by the secondary electron emission it caused in a beryllium-copper electrode.

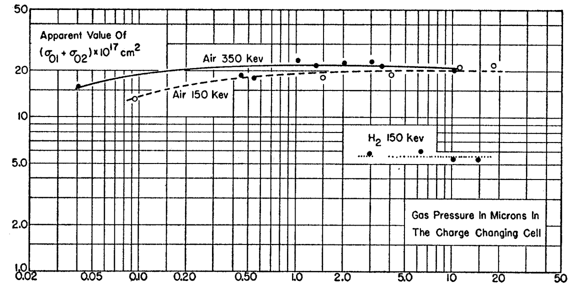

FIG. 2. Total charge-changing cross sections measured for neutral helium atoms prepared from a He^+ beam at various pressures in the charge-changing cell.

RESULTS

A. Possible Dependence of the Composition of the Neutral Beam on Pressure in the Charge Changer

The cross sections $(\sigma_{01}+\sigma_{02})$ observed for neutral helium beams prepared with different charge-changing cell pressures are shown in Fig. 2. In testing the attenuation of the neutral beam, the same gas (air or H_2) was used in the measuring cell as in the charge-changing chamber. It is seen that, using air and a 350-kev neutral beam, there is a pressure region extending from 0.7 to 10 microns through which the attenuation cross section of the neutral beam shows no trend away from the mean value of 22×10^{-17} cm^2. Four attenuation observations on 150-kev neutrals produced in air show no decisive trend from the mean value 21×10^{-17} cm^2 between pressures of 1.5 and 19 microns in the charge-changing cell. A similar pressure independence is shown between 3 and 15 microns for He^0 beams produced in H_2 gas. Barnett and Stier[1] found pressure independence for a 100-kev neutral beam produced from He^+ in H_2 extending from about 15 to at least 35 microns pressure, but below this the cross section for attenuation apparently increased.

For lower pressures in the charge-changing cell, between 0.04 and 0.50 micron, Fig. 2 shows that apparently the cross section $(\sigma_{01}+\sigma_{02})$ has decreased. A decrease is to be expected for the following reason. About 2.5 microns of air were admitted to the measuring chamber to test the attenuation of the neutral beam. The pressure drop from one differential pumping chamber to the next was about 10-fold; hence increases of pressure of the order of 0.25μ and 0.025μ were produced in the differential pumping compartments between the measuring and charge-changing chambers,

[4] Allison, Cuevas, and Murphy, Phys. Rev. 102, 1041 (1956).

TABLE I. Electron loss cross sections for helium atoms (in units of 10^{-17} cm^2 per atom of gas traversed).

Kinetic energy (kev)	Hydrogen $(\sigma_{01}+\sigma_{02})$	Hydrogen σ_{02}	Helium $(\sigma_{01}+\sigma_{02})$	Helium σ_{02}	Air $(\sigma_{01}+\sigma_{02})$	Air σ_{02}
100	4.2	...	7.5	...	16.4	...
150	5.8	...	8.9	...	21.2	0.2 ± 0.2
250	5.7	0.1 ± 0.1	9.7	0.2 ± 0.2	23.2	0.5 ± 0.4
350	6.0	<0.1	8.4	<0.2	22.0	0.8 ± 0.5
450	7.0	<0.1	8.2	<0.2	24.5	1.3 ± 0.4

and these were significant increases in the low pressures previously there. The low pressure in the charge-changing cell meant that the He^0 fraction was far below its equilibrium value; hence the pressure increase produced more He^0 in the beam incident on the measuring cell and the uncorrected attenuation would give low cross sections from this effect alone. Thus any increase in cross section due to a higher fraction of metastable atoms at these low pressures, as found by Barnett and Stier,[1] may have been masked by this pressure backup effect. The measurements of the cross-section sum $(\sigma_{01}+\sigma_{02})$ reported below were made in the pressure-independent region as established in Fig. 2.

B. The Electron Loss Cross Sections $(\sigma_{01}+\sigma_{02})$

An investigation of the ratio

$$\epsilon'=\sigma_{02}/(\sigma_{01}+\sigma_{02}) \tag{2}$$

for helium ions has recently been reported,[5] showing that ϵ' is 0.02 ± 0.02 in hydrogen, helium, and air for 250-kev helium atoms, less than 0.01 in hydrogen and helium at 450 kev, and 0.06 ± 0.02 in air at 450 kev. These values have been used in Table I, which contains the remeasured cross sections.[6]

It is estimated that the cross section sums $(\sigma_{01}+\sigma_{02})$ are correct within 10%.

[5] S. K. Allison, Phys. Rev. **109**, 76 (1958).
[6] Some of these have appeared in Table VI of a previous paper.[5]

DISCUSSION

Although the cross sections of Table I show the same trend with kinetic energy, and the same ratios between the gases H_2, He, and air as those previously reported,[2] they are systematically lower in absolute value. In the region 100–200 kev where they can be compared with the measurements of Barnett and Stier there is very good agreement. The results of Barnett and Stier[1] have been used in Fig. 3 to construct curves of the total charge-changing collision of helium atoms from 4 to 450 kev.

Theoretical computations have been made for the electron loss cross section for moving hydrogen atoms,

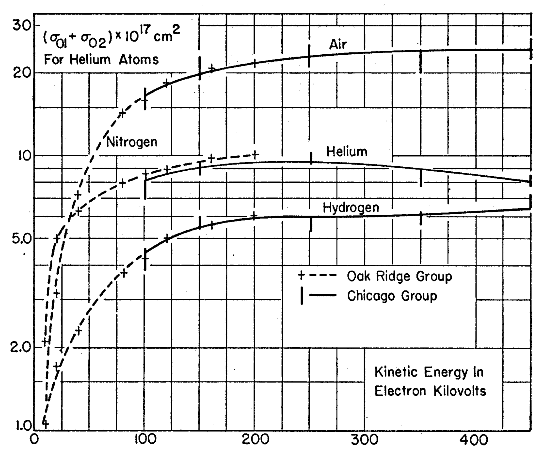

FIG. 3. The total charge-changing cross section for helium atoms in the kinetic energy range 4 to 450 kev.

and for He^+ ions in motion, but calculations on electron loss from moving helium atoms seem not to be available.[7,8]

ACKNOWLEDGMENTS

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[7] D. R. Bates and A. Williams, Proc. Phys. Soc. (London) **A70**, 306 (1957).
[8] D. R. Bates and G. W. Griffing, Proc. Phys. Soc. (London) **A68**, 90 (1955).