Charge Equilibrium of Helium Ions in Helium Gas from 60 to 840 keV*

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Charge equilibrium fractions corresponding to the components $(He)^0$, $(He)^+$, and $(He)^{++}$ of a helium beam in helium gas have been measured. Singly ionized beams of He^4 and doubly ionized beams of He^3 were used. Ion velocities covered the range corresponding to energies of $(He^4)^+$ ions from 60 to 840 keV. The charge-equilibrated beam was magnetically separated and charge spectra were recorded by means of a movable detector of equal sensitivity for all three charge components. In the energy interval where they overlap, namely between 60 and 200 keV, the measured equilibrium fractions are in excellent agreement with those of Barnett and Stier. No systematic discrepancy between the equilibrium fractions obtained at equal velocities with beams of the isotopes He^3 and He^4 was observed. The results were discussed in terms of the probabilities M_{I} for presence of any one of the two electrons in $(He)^0$ and M_{II} for presence of the one electron in $(He)^+$ as a function of the beam velocity v. Similarity of the curves for M_{I} and M_{II} allows for their superposition by a translation transformation on the velocity scale by a constant approximately equal to the "orbital" velocity u_{I} of either electron in $(He)^0$ as calculated from its first ionization energy. This is in disagreement with Dmitriev's assumption that the presence probabilities M_i can be described by a universal function $M(v/u_i)$.

I. INTRODUCTION

IN an ionic beam traversing matter, collisions occur in which electrons are interchanged between the projectiles and the target atoms. The probabilities of such charge-changing collisions are described by cross sections σ_{if}, i and f being the number of positive unit charges of the ion before and after the collision.

If we denote by F_i the fraction of the total beam particle flux which is in the charge state i, then the rate of change of these fractions as a function of the thickness π (atoms/cm^2) traversed is given by a set of simultaneous differential equations of the form

$$\frac{dF_i}{d\pi}=-F_i\sum_{j\pm i}^{z}\sigma_{ij}+\sum_{k\pm i}^{z}F_k\sigma_{ki}.$$

The first right-hand term is due to electron losses or captures from the state i, the second to electron captures or losses leading to the state i.

When the beam has traversed a layer of sufficient thickness, these capture and loss processes cancel each other and a state of dynamic charge equilibrium is reached for which "charge equilibrium fractions" $F_{i\infty}$ are characteristic.

Tabulated values of charge equilibrium fractions $F_{i\infty}$ and charge-exchange cross sections σ_{if} for hydrogen and helium beams in different gases are given in a well-known review article by Allison[1] which summarizes the data available up to 1958. This information remains practically unchanged in a more recent review article by Allison and García Muñoz.[2]

These tables include charge equilibrium fractions $F_{0\infty}$, $F_{1\infty}$, $F_{2\infty}$ of He beams in He gas. From 8 to 200 keV the information is based on measurements of Stier, Barnett, and Evans[3] and of Barnett and Stier.[4] Their results, obtained by different procedures, are remarkably consistent.

Snitzer[5] measured the charge equilibrium fractions $F_{0\infty}$, $F_{1\infty}$, and $F_{2\infty}$ of He in He gas between 100 and 480 keV. The agreement with Barnett and Stier is poor; discrepancies as large as 30% occur.

From 200 to 480 keV, Allison's tabulated equilibrium fractions are based, not on Snitzer's measurements, but on values computed from charge-exchange cross sections measured by his group in Chicago.[6] Such an indirect determination of equilibrium fractions, however, is in principle subject to larger errors than a direct measurement. At 200 keV, where they overlap, the $F_{i\infty}$ computed from cross sections are about 10% lower for $F_{0\infty}$, 10% higher for $F_{1\infty}$, and 15% higher for $F_{2\infty}$ when compared to the directly measured values of Barnett and Stier. In accordance with this discrepancy, a distinct discontinuity in the equilibrium fractions tabulated by Allison[1] is observed above 200 keV.

Pivovar, Tubaev, and Novikov[7] give tables of their measured equilibrium fractions of a He beam in He gas in steps of 100 keV between 200 and 1500 keV. Their agreement with Allison's computed values is good.

* This work was supported in part by the National Science Foundation.

[1] S. K. Allison, Rev. Mod. Phys. **30**, 1137 (1958).

[2] S. K. Allison and M. García Muñoz, *Atomic and Molecular Processes* (Academic Press Inc., New York, 1962), p. 721 ff.

[3] P. M. Stier, C. F. Barnett, and G. Evans, Phys. Rev. **96**, 973 (1956).

[4] C. F. Barnett and P. M. Stier, Phys. Rev. **109**, 385 (1958).

[5] E. Snitzer, Phys. Rev. **89**, 1237 (1953).

[6] S. K. Allison, J. Cuevas, and P. G. Murphy, Phys. Rev. **102**, 1041 (1956); S. K. Allison, *ibid.* **109**, 76 (1958).

[7] L. I. Pivovar, V. M. Tubaev, and M. T. Novikov, Zh. Eksperim. i Teor. Fiz. **41**, 26 (1961) [English transl.: Soviet Phys.—JETP **14**, 20 (1962)].

Nicolaev and co-workers[8] measured the charge equilibrium of a He beam in He gas at 4 different energies, namely, 0.665, 1.30, 2.82, and 5.87 MeV. They claim agreement with Allison's[1,2] tables at 0.35 MeV, but do not give numerical values for this energy.

Taking into account the discrepancies among the results of different authors rather than their quoted errors, it is doubtful whether charge equilibrium fractions of He beams in He gas are known with a precision better than $\pm 10\%$, the error limit for $F_{2\infty}$ being probably larger at low energies where its value is smaller than 0.02.

A possible source of discrepancies might have been the use of different detectors for the different magnetically or electrically separated charge components. When secondary-electron-emission detectors were used, their sensitivity for the neutral component had to be checked by thermal devices.

It therefore appeared to be of interest to remeasure the charge equilibrium fractions of a He beam in He gas, by using a technique in which one detector surveys all charge components and by assuring that the detection efficiency is the same for particles of different charge, including the neutrals.

As the high voltage of the Bariloche Cockcroft-Walton accelerator is limited to 310 kV, to extend the measurements to higher energies it was necessary to use a doubly charged beam and—for reasons to be explained—a doubly charged beam of He^3.

This leads to the question whether projectiles of the same velocity but of different isotopic mass are subject to the same charge-exchange probabilities. This assumption is generally accepted because electrostatic forces alone are involved in the interaction during a collision. As there is only a momentum transfer of a loosely bound electron, practically all the contribution to charge exchange is at very small angles and the time dependency of the collision process is determined only by the initial relative velocity between projectile and target atom, irrespective of their mass.

Although known charge-exchange cross-section calculations do not depend on the isotopic masses of the colliding particles, there is, however, an ambiguity in the experimental evidence concerning this subject.

Hall and Warshaw,[9] Philips,[10] and Meckbach and Allison[11] obtained equal atomic stopping power for $(H)^+$ and $(D)^+$ beams of equal velocity, showing that the effective charge in these beams was not affected by the mass difference between H and D. Fite, Brackmann, and Snow[12] obtained good agreement between capture cross sections of $(H)^+$ and $(D)^+$ ions of equal velocities interacting with D_2; however, systematic discrepancies seemed to appear when the interaction is with atomic deuterium.

Recently, Hollrichter[13] studied the existence of an "isotope effect," comparing at equal velocities the capture cross section σ_{10} of protons and deuterons in H_2 and D_2 gas for energies up to 30 keV. For a deuteron beam his measured cross sections were about 8% lower than for a proton beam. The cross sections were higher in D_2 than in H_2 gas. He concludes that the combination light-projectile–heavy-target leads to higher capture (lower loss) cross sections and vice versa.

A possible dependency of charge exchange on the isotopic mass must be of less significance between He^3 and He^4, as compared to H and D, but according to the results of Hollrichter a systematic discrepancy should be clearly distinguishable in the He case if measurements are consistent within less than 2%.

In the present work the charge equilibrium fractions $F_{0\infty}$, $F_{1\infty}$, and $F_{2\infty}$ of a helium beam in helium gas are measured in the energy range 60 to 840 keV. Between 160 and 300 keV, where they overlap, the measurements permit a comparison of the charge equilibria obtained with He^4 and He^3 beams of equal velocity.

This work does not include measurement of the negative beam component. Jorgensen *et al.*[14] obtain for the equilibrium fraction of $(He)^-$ ions in helium gas the value $F_{\bar{1}\infty}=0.8\times10^{-4}$ at 200 keV, where it reaches a broad maximum. In the present work the smallest equilibrium fraction measured at this same energy is $F_{2\infty}=0.02$. Evidently the error introduced by neglecting $F_{\bar{1}\infty}$ is negligible.

II. MEASURING EQUIPMENT AND PROCEDURE

A schematic drawing of the measuring equipment is shown in Fig. 1.

The Bariloche Cockcroft-Walton accelerator delivers an approximately parallel beam of about 4-mm diam.

The desired beam component is sorted out by magnetic deflection. The deflected beam traverses cold trap 1 and penetrates into the interaction cell consisting of a brass tube 28 cm long and 3 cm in diam. Gas is injected through a needle valve. A rough indication of the pressure in the cell is obtained from a thermocouple gauge. This pressure varied between 20 and 60 μ Hg.

The beam enters, and leaves the interaction cell through channels 1 and 2 which are 1.2 mm in diam and 10 mm long. At their upstream end the width of these channels is reduced to 1 mm. The beam-limiting holes thus formed present a sharp edge to the incoming beam. In this way scattering and eventual additional charge-changing events produced on metallic surfaces are reduced to a minimum.

[8] V. S. Nicolaev, I. S. Dmitriev, L. N. Faateva, and Y. A. Teplova, Zh. Eksperim. i Teor. Fiz. **39**, 905 (1960) [English transl.: Soviet Phys.—JETP **12**, 627 (1961)].
[9] T. A. Hall and S. D. Warshaw, Phys. Rev. **75**, 891 (1949).
[10] J. A. Philips, Phys. Rev. **97**, 404 (1955).
[11] W. Meckbach and S. K. Allison, Phys. Rev. **132**, 294 (1963).
[12] W. L. Fite, R. T. Brackmann, and W. R. Snow, Phys. Rev. **112**, 1161 (1958).
[13] O. Hollrichter, Z. Physik **187**, 41 (1965).
[14] T. Jorgensen, Jr., C. E. Kuyatt, W. W. Lang, D. C. Lorents, and C. A. Sautter, Phys. Rev. **140**, A1481 (1965).

The charge-equilibrated beam traverses cold trap 2 and passes through a ring-shaped monitor electrode, on which only scattered beam particles are collected.

The beam is finally separated into its individual charge components by magnetic deflection.

The pole pieces of the beam-sorting magnet and of the beam-analyzing magnet are shaped to allow for double focusing by the fringing field.[15] Thus the beam is kept almost parallel along its path through the measuring equipment. This minimizes intensity losses and scattering at the diaphragms due to beam divergence. Vacuum is maintained in the equipment by two independent vacuum systems 1 and 3 with their corresponding cold traps (not shown in Fig. 1). At the downstream end of the beam equilibrium cell, differential pumping is applied between channels 2 and 3. Channel 3, of 1.3 mm diam, is not touched by the beam. With "gas out," the pressure in the analyzing chamber was about 2×10^{-6} mm Hg; it increased with "gas in" to not more than 8×10^{-6} mm Hg.

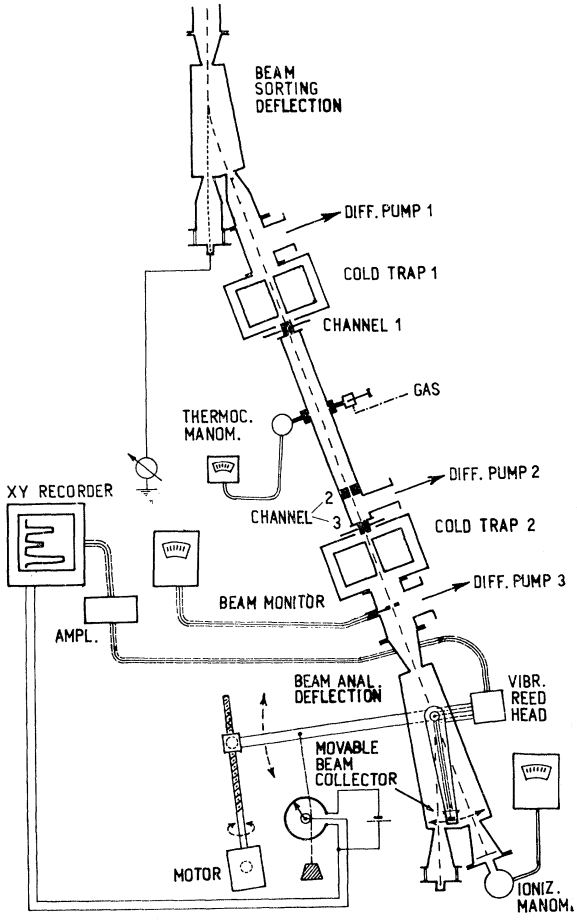

FIG. 1. Schematic diagram of the experimental equipment.

[15] W. G. Cross, Rev. Sci. Instr. **22**, 717 (1951).

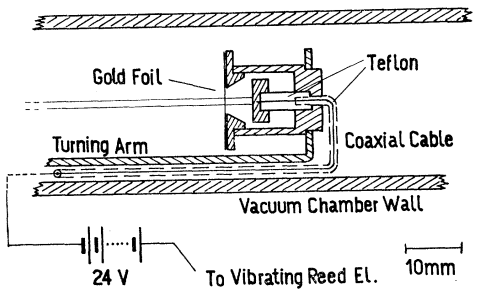

FIG. 2. Detail of the beam collector for detection of ions of different charge and neutrals with equal efficiency.

A movable detector permits a survey of the magnetically separated components of the charge-equilibrated beam.

This method used by Philips[10] presents advantages when compared with the method of two or three fixed detectors. First, the same detector is used for all beam components; no comparison of the efficiency of different detectors, as described by Allison,[1] is necessary. Second, as the magnet field is not changed during a measurement, there is substantially no variation of stray magnetic fields which may affect the collection of secondary electrons.

Figure 2 shows the ion collector in more detail. In order to obtain the same detection efficiency for all charge components, including the neutrals, a method proposed by Allison[1,16] has been adopted.

When entering the ion detector each beam component has to traverse a thin gold foil in which it is again charge equilibrated. As this new charge equilibrium does not depend on the charge of the incoming beam particles, the collection of charge by the beam-collecting electrode and the consequent release of secondary electrons will be proportional to the number of particles impinging upon the detector. A negative bias of -24 V is applied to the beam-collecting electrode. (Saturation of the secondary electron collection was reached at -15 V.) In this way the secondary electrons from the beam collector contribute to the measured positive current.

The movable beam collector is mounted on the end of a turning arm (Fig. 1), the axis of which traverses the vacuum chamber wall and the perforated pole piece of the deflecting magnet. The motion of the ion collector is controlled by a motor-driven arm fixed to the outer end of the turning axis, as shown.

This axis is also a coaxial line through which the current signal from the ion collector is transmitted. The current is measured by means of a vibrating-reed electrometer. The signal from the vibrating-reed preamplifier unit is applied to an XY recorder. The chart movement signal is provided by a helipot potentiometer driven by a nylon string attached to the outer moving

[16] S. K. Allison and S. D. Warshaw, Rev. Mod. Phys. **25**, 779 (1953).

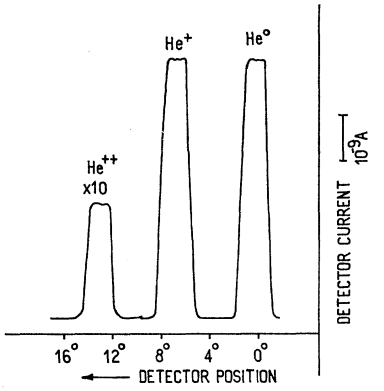

FIG. 3. Typical charge spectrum taken with a 210-keV initial $(He^4)^+$ beam. Flat peaks indicate 100% detection of each charge component. No detectable background between peaks is observed.

lever (Fig. 1). In this simple manner the recorder chart movement is synchronized with the angular deflection of the beam collector, and "charge spectra" of the equilibrated beam are displayed directly. One such spectrum is seen in Fig. 3. The desired charge equilibrium fractions result from the individual peak heights divided by their sum.

III. MEASUREMENTS AND PRECISION

Feeding the rf ion source of the accelerator with He^4 gas, and using the singly charged $(He^4)^+$ beam, measurements of charge equilibrium fractions $F_{0\infty}$, $F_{1\infty}$, and $F_{2\infty}$ were performed between 60 and 300 keV. It is in principle possible to double the beam energy by using the component of doubly charged ions $(He^4)^{++}$ put out by the ion source. However, as the charge-to-mass ratio of $(He^4)^{++}$ is the same as that of molecular hydrogen ions $(H_2)^+$ always present in the beam, the doubly charged helium beam cannot be magnetically separated. After dissociation and charge equilibration, the $(H_2)^+$ beam produces neutrals $(H)°$, which are not deflected in the field of the beam-analyzing magnet and remain superposed with the neutral component of the helium beam.

In order to make measurements with doubly charged He ions possible, the isotope He^3 was fed into the ion source. The $(He^3)^{++}$ beam could be separated by deflection in the sorting magnet.

Let us assume that at equal velocities charge-exchange cross sections, and therefore equilibrium fractions, are independent of the isotopic mass of the bombarding particles. For a $(He^3)^{++}$ ion of a certain velocity, we than can define an "equivalent energy" as the kinetic energy of a $(He^4)^+$ ion which has the same velocity as the $(He^3)^{++}$ ion and is therefore subject to the same charge equilibration. This equivalent energy is $\frac{4}{3}$ times the true energy of the $(He^3)^{++}$ ion and, because of its double charge, is numerically equal to $2\times\frac{4}{3}=2.667$ times the accelerator voltage. The maximum accelerator voltage of 310 kV permitted the equilibrium fraction measurements to be extended up to an equivalent energy of 830 keV. Measurements made with the $(He^3)^{++}$ and $(He^4)^+$ beams do overlap in the energy range 160 to 300 keV.

The main cause for statistical errors were fluctuations in the beam intensity, normally of the order of $\pm 1\%$ in the case of the $(He^4)^+$ beam and somewhat less than $\pm 2\%$ in the case of the $(He^3)^{++}$ beam.

As each sweep of a charge spectrum took only about $\frac{1}{2}$ min, slow time-dependent variations of the beam intensity were not critical. The beam monitor (Fig. 1) was used only to check the beam stability. The short duration of each run made repetition of measurements easy to obtain good statistics. For the measurements up to 300 keV, statistical errors were of the order of 1% for $F_{0\infty}$ and $F_{1\infty}$, 2% for $F_{2\infty}$. Because of larger beam fluctuations at higher energies, random errors were of the order of 3%. These random errors would be accepted as error limits for the present measurements only if no systematic effects escaped observation. A search for possible sources of systematic errors will be described.

Particularly satisfying was the appearance of flat peaks in the charge spectra as seen in Fig. 3. It shows that the cross sectional area of each impinging beam component (approximately 2 mm in diam as observed on a fluorescent screen) was smaller than the 6-mm aperture of the beam collector. Thus the collection efficiency for all charge components was the same and equal to 100%.

The "zero deflection" between charge peaks was reproduced if the beam was removed and also coincided with the "true zero" of the vibrating-reed electrometer.

The purity of the helium injected into the interaction cell was guaranteed by the manufacturer to be better than 0.998. Before any measurement was performed, the interaction cell was outgassed and then flushed for 3 h with a continuous stream of helium gas.

To be sure that the gas-target thickness was sufficient to charge equilibrate the beam, the charge fractions F_0, F_1, and F_2 were measured at various energies as a function of the pressure in the interaction cell.

Test runs showed that the sum of the recorded peak heights corresponding to the $(He)°$, $(He)^+$, and $(He)^{++}$ components of the charge-equilibrated beam was equal to that of the total undeflected beam, measured after careful elimination of the residual beam-analyzing field.

To show that the measured charge equilibria were not affected by scattering on the beam-limiting diaphragms due to beam divergence, experiments with a purposely defocussed beam were performed, thereby reducing the beam intensity by two orders of magnitude. They did not result in a change of the previously measured equilibrium fractions.

When sorting out magnetically the doubly charged He^3 beam of relatively reduced intensity, it was important to show that the intensity of the "tails" from much stronger adjacent beams $[(H)^+,(H_2)^+]$ was less than 0.2% of the height of the desired $(He^3)^{++}$ peak.

Linearity of response and compatibility between

ranges of the vibrating-reed electrometer were checked to be within $\pm 2\%$.

A voltage divider, consisting of a shunted microammeter in series with a 4000-MΩ chain resistance served to read the accelerator voltage. These voltage readings were calibrated against the sorting magnetic field necessary for the 20° deflection through the apparatus. A reference voltage was obtained from the reaction $B^{11}(p,\gamma)C^{12}$, which is known to have a strong resonance at (163.1 ± 0.5) keV.[17]

It is worth mentioning that for the target-gas thicknesses used in this work, the total energy attenuation of the beam traversing the interaction tube did not exceed 0.3% and was generally less than 0.2% of the beam energy.

IV. RESULTS AND DISCUSSION

In Fig. 4 the measured charge equilibrium fractions $F_{0\infty}$, $F_{1\infty}$, and $F_{2\infty}$ are plotted as a function of beam energy between 60 and 840 keV. Error bars are drawn only for the measurements made with the $(He^3)^{++}$ beam. For the $(He^4)^{+}$ data, statistical errors associated with the measurements are smaller than the diameter of the plotted points.

It is seen that throughout the energy range of overlap (60–200 keV) the coincidence with the results of Barnett and Stier[3,4] is excellent. Deviations are small compared with the random errors of the present measurements which in this energy range are less than 1% for $F_{0\infty}$ and $F_{1\infty}$, and about 2% for $F_{2\infty}$. Only at the lowest energies where $F_{2\infty}$ is small, is disagreement in this component more significant, amounting up to 10% at 60 keV.

For energies between 200 and 500 keV, we compare our results with the equilibrium fractions computed from cross sections by Allison[1,2] and with the measurements of Pivovar *et al.*[7]

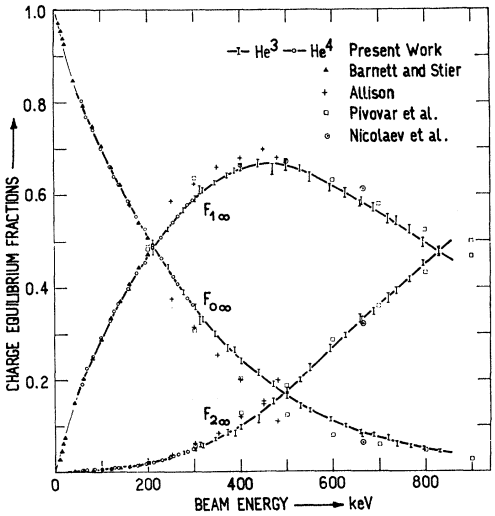

FIG. 4. Charge-equilibrium fractions $F_{0\infty}$, $F_{1\infty}$, and $F_{2\infty}$ of He ions in He gas between 60 and 840 keV. Measurements made with the $(He^3)^{++}$ beam are plotted at $\frac{4}{3}$ of their actual energy.

[17] J. B. Marion, Rev. Mod. Phys. 33, 139 (1961).

TABLE I. Charge-equilibrium fractions as resulting from graphical interpolation of the present measurements.

E (keV)	v (10^8 cm sec^{-1})	$F_{0\infty}$	$F_{1\infty}$	$F_{2\infty}$
60	1.70	0.792	0.204	0.0043
100	2.20	0.702	0.290	0.0064
140	2.60	0.619	0.370	0.0096
180	2.95	0.542	0.440	0.0153
220	3.26	0.474	0.500	0.0238
260	3.54	0.414	0.548	0.0360
300	3.81	0.358	0.591	0.051
340	4.05	0.307	0.623	0.069
380	4.29	0.266	0.647	0.086
420	4.51	0.228	0.662	0.109
460	4.72	0.193	0.668	0.139
500	4.92	0.164	0.663	0.174
540	5.11	0.139	0.650	0.212
580	5.30	0.119	0.629	0.252
620	5.48	0.103	0.607	0.290
660	5.65	0.087	0.585	0.327
700	5.82	0.075	0.562	0.363
740	5.98	0.065	0.536	0.399
780	6.14	0.055	0.509	0.434
820	6.30	0.047	0.482	0.471
840	6.38	0.043	0.468	0.488

Agreement between these authors is good, except near 500 keV, where discrepancies amount to more than 15%. The present results give lower values to $F_{1\infty}$ and $F_{2\infty}$, and higher values to $F_{0\infty}$ where differences are larger, amounting to 20% at 500 keV. However, there is agreement between Pivovar and this work in the maximum value assigned to $F_{1\infty}$, whereas that given by Allison is higher. At energies above 500 keV, discrepancies between our results and Pivovar's become smaller for $F_{1\infty}$ and $F_{2\infty}$, whereas for $F_{0\infty}$ better agreement is reached only above 700 keV. Measurements of Nicolaev and co-workers[8] can be compared with the present work at 665 keV. At this single energy, agreement in $F_{2\infty}$ is satisfactory, whereas their value for $F_{0\infty}$ is lower and for $F_{1\infty}$ higher than our measured values.

In Table I the charge equilibrium fractions as resulting from graphical interpolation in Fig. 4 are tabulated.

Dmitriev[18] has given a phenomenological description for charge equilibrium in terms of probabilities P for a given electron to be absent from the ion and probabilities $M=1-P$ for its being present.

Dmitriev first assumes that the probability of absence of a given electron is independent of the presence or absence of other electrons in the projectile. Under this assumption it is possible to express the charge equilibrium fractions in terms of these presence and absence probabilities. In the case of helium we have

$$F_{0\infty}=M_{\mathrm{I}}M_{\mathrm{II}},$$

$$F_{1\infty}=M_{\mathrm{I}}P_{\mathrm{II}}+P_{\mathrm{I}}M_{\mathrm{II}}=M_{\mathrm{I}}(1-M_{\mathrm{II}})+(1-M_{\mathrm{I}})M_{\mathrm{II}},$$

$$F_{2\infty}=P_{\mathrm{I}}P_{\mathrm{II}}=(1-M_{\mathrm{I}})(1-M_{\mathrm{II}}).$$

[18] I. S. Dmitriev, Zh. Eksperim. i Teor. Fiz. 32, 570 (1957) [English transl.: Soviet Phys.—JETP 5, 473 (1957)].

The question arises of what is meant here by "independent probabilities." If we assign these probabilities to a given electron in the atom, then, in the neutral helium atom (He)°, the probability of absence (or presence) for any one of its two electrons is obviously the same. But, once one electron is gone, the probability of absence (or presence) for the electron left in the $(He)^+$ ion is quite different.

In fact, according to Dmitriev, the probabilities P_i are actually determined by the different ionization energies I_i of the ion. This statement is contained in his second assumption, that is, the probabilities P_i can be expressed in terms of an universal function $P(v/u_i)$ of the ion velocity v in units of a velocity $u_i=(2I_i/m)^{1/2}$ which, according to Lamb[19] is a measure of the orbital velocity of the electron considered.

Solving the above systems of equation for the presence probabilities M in terms of the equilibrium fractions $F_{i\infty}$, a quadratic equation is obtained. Physically, the two roots of this equation are to be assigned to the probabilities M_{I} for keeping any one of the two electrons in (He)°, and M_{II} for the presence of the one electron left in $(He)^+$. These probabilities (or the corresponding "absence probabilities" P_{I} and P_{II}) are independent of each other.

In Fig. 5 the probabilities MI and MII, as determined from our measured charge equilibrium fractions, are represented as a function of the ion velocity v.[20] At all velocities, M_{I} and M_{II} turned out to be real quantities. Both probabilities are monotonically decreasing functions of v. As charge equilibration is mainly governed by capture and loss of single electrons, the probability M_{II} for the presence of one electron remains high until M_{I} has decreased sufficiently to make electron release from the ion $(He)^+$ probable.

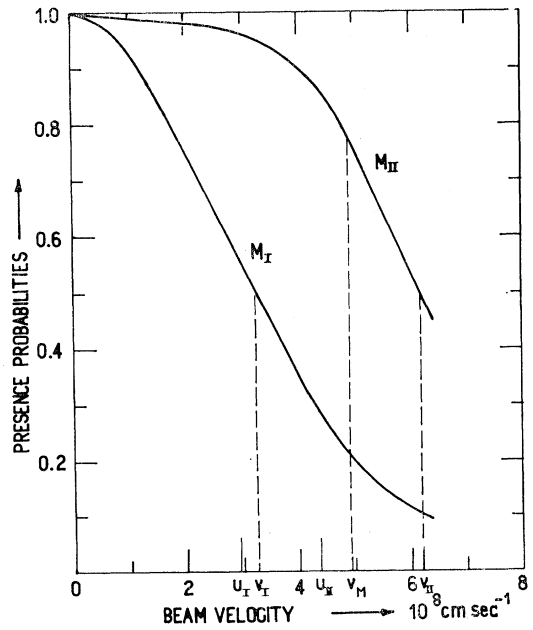

FIG. 5. Presence probabilities M_{I} for keeping one of the two electrons in (He)°, and M_{II} for the electron in $(He)^+$ as a function of the ion velocity. u_{I} and u_{II} are approximate values of the orbital velocities in (He)° and in $(He)^+$ calculated from the corresponding ionization energies.

A striking similarity between both curves is observed; in their straight sections they are of almost equal slope. M_{I} reaches the value $\frac{1}{2}$ at a velocity v_{I} which is 10% larger than the velocity u_{I} corresponding to the first ionization potential I_{I} of helium. The probability $P_{\mathrm{I}}=1-M_{\mathrm{I}}$ for the absence of an electron from (He)° equals M_{II}, the probability for keeping the electron left in $(He)^+$, at a velocity v_M which is about 10% larger than u_{II}, the velocity corresponding to the second ionization potential. v_M corresponds to the energy at which $F_{1\infty}$ reaches its maximum value in Fig. 4. It is surprising that M_{II} reaches the value $\frac{1}{2}$ when the ion velocity is almost exactly $v_{\mathrm{II}}=2v_{\mathrm{I}}$. In fact, one can even make a large part of both curves coincide by the simple translation transformation $v'=v-v_{\mathrm{I}}$ for M_{I}.

Dmitriev's second assumption implies that M_{I} could be transformed into M_{II} by $v'=hv$ $(h=u_{\mathrm{II}}/u_{\mathrm{I}})$. This is clearly seen to be impossible if one looks at the curves of Fig. 5.

We finally observe that in Fig. 4 the coincidence of the charge equilibrium fractions measured with $(He^4)^+$ and $(He^3)^{++}$ beams of equal velocity is excellent throughout the energy range (160–280 keV) where they overlap, the deviations being small in comparison with statistical errors. We can therefore assume that no "isotope effect" is observed within error limits of less than 1.0% for $F_{0\infty}$ and $F_{1\infty}$, and 2% for $F_{2\infty}$. This seems to contradict the results obtained by Hollrichter[13] with the isotopes hydrogen and deuterium. It is in agreement with recent measurements of Armstrong *et al.*,[21] who have determined the charge equilibrium of He beams in carbon between 0.2 and 6.5 MeV. These authors also made measurements with beams of He^3 and He^4 and found no isotope effect within the remarkable consistency of their measurements.

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