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THE PROPERTIES OF THE PHOTO-ELECTRIC CURRENT IN GASES

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ABSTRACT

The spatial properties of photo-electric current between parallel plate electrodes were measured in He, Ar, Ne and N_2 and the behaviour of electrons with low mean energy was also simulated by Monte-Carlo method in He, Ar and N_2.

The experimental and computational results revealed that back-scattering of electrons in front of the cathode decides the spatial properties of photo-electric current in gas at low applied voltage.

1. Introduction

The spatial growth of the pre-breakdown current in uniform electric fields can be described by the TOWNSEND equation and the primary and secondary ionization coefficients can be determined by this equation[1]. To determine the secondary coefficient, however, one must choose the value corresponding to the initial current included in the equation from the measured current growth. So far the saturated plateau in V-I characteristic has been chosen as the initial current[2].

The saturated plateau, however, cannot always be obtained by such experiments that the initial electrons are ejected from the cathode by ultra-violet irradiation, and there always exists ambiguousness in determining the initial current. As far as the authors know there is no investigation on this subject and it is necessary to clarify the mechanism which takes place. This subject, furthermore, is very interesting from the point of view of the phenomena at the boundary between cathode and gaseous phase in gas discharges.

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* This report has been prepared for the seminar held by Keio University at the opportunity of Prof. LOEB's visit ; a part of this description will be published in the Transaction of IEE of Japan (in Japanese).

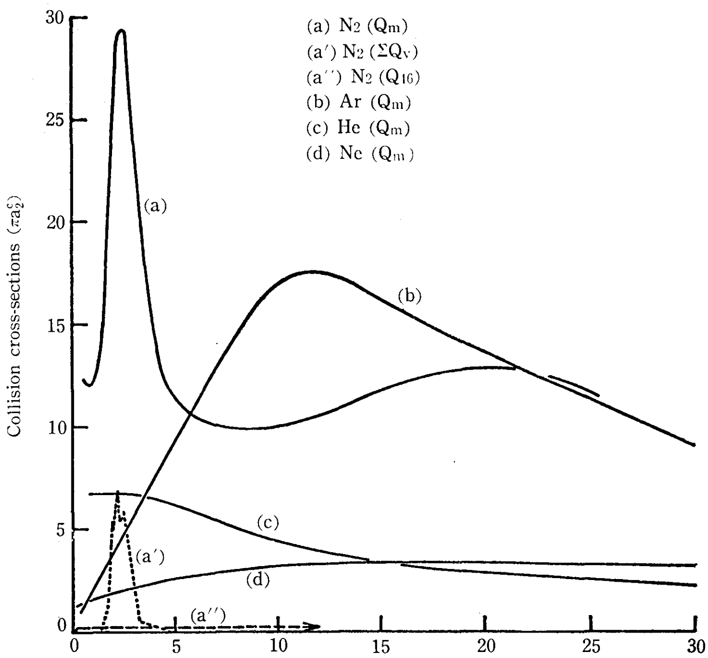

Fig. 1. Collection of cross-sections of atoms investigated.
The cross-sections of electronic excitations are excluded.

The V-I characteristic of one gas in low voltage is different from that of another gas, but this complexity may imply the importance of collision interactions between ejected electrons and gas atoms surrounding the cathode.

From this point of view the spatial properties of photo-electric current were measured in He, Ar, Ne and N_2 and the behaviour of ejected electrons with low energy was also simulated by the Monte-Carlo method in He, Ar and Ne.

Collision interactions of electrons with these gases are well known. Rough features of collision cross-sections of gases investigated here are shown in Fig. 1[3] and it can be seen that they are quite different one another. As the incident energy of electron increases, the momentum transfer cross-sections of Ar and Ne increase and that of He, on the other hand, decreases. The magnitude of the cross-section of Ar is larger than that of Ne. The typical feature of the cross-section of molecular nitrogen is the considerable contribution of its vibrational excitation in low energy range. It is supposed that these distinct cross-sections should cause individual V-I characteristics and that is the reason why these four gases were chosen in this experiment.

The experimental results and the comparison of them with the results of the simulation showed that the effect of the back-scattered electrons to the cathode was important on the V-I characteristic of the photo-electron current in low voltages.

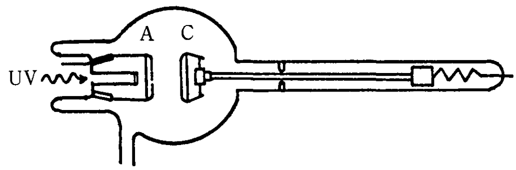

Fig. 2. The cross-section of the ionization tube

2. Experiments

Fig. 2 shows the cross-section of the ionization chamber.

The electrode system was made of nickel and consisted of a parallel anode and cathode whose separation could be varied from out side. The cathode was irradiated by the ultra violet lamp through nine holes made in the center of the anode.

The experimental procedure was to measure the relation between the photo-electric currents and the applied voltages in each gas. Before and after every measurement in gas the photo-current characteristic in vacuum was measured and it was confirmed that the measurement in the gas did not change the cathode surface condition.

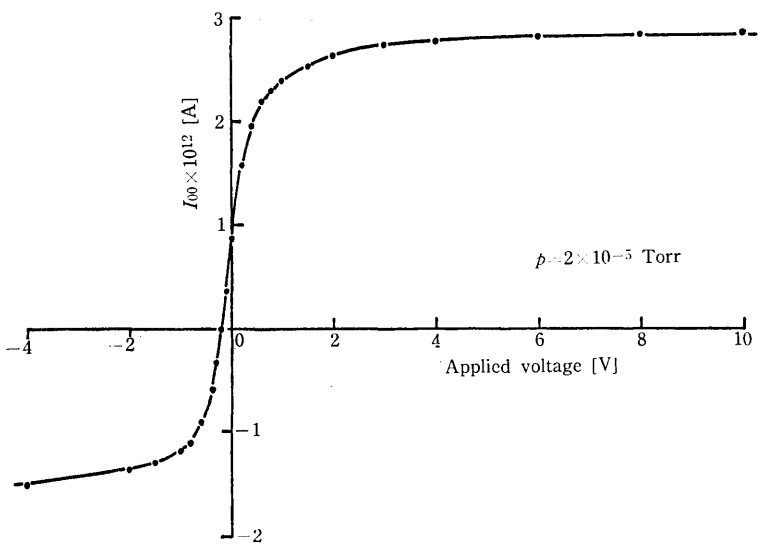

Fig. 3. An example of the characteristic of photo-electric current in vacuum.

3. Results

(1) Experimental results

Fig. 3 shows an example of the photo-electronic current in vacuum (I_{00}). I_{00} was used to normalized the current in gas because I_{00} was proportional to the number of electrons released from the cathode in absence of surrounding gas atoms and the normalized results might show the effect of the atoms separately.

Fig. 4 shows the result in nitrogen. No saturated plateau could be found. The results were transformed into the relation between the normalized current and E/P_0 (E stands for the electric field and P_0 for the gas pressure reduced to 0°C) to make easier to understand them. Figs. 5, 8, 10 and 12 show the results in nitrogen, argon, helium and neon, respectively.

These figures were further transformed to the so-called TOWNSEND plot[1] in Figs. 7, 9, 11 and 13.

Fig. 6 shows the effect of the gap separation (*d*) to the relation between the normalized current and E/P_0.

When the electronic loss due to radial diffusion cannot be ignored, the normalized current in Fig. 6 must depend on *d*, because the diffusion phenomena must obey the similarity law and the experimental condition does not satisfy this law. As little dependence could be found in Fig. 6, the electronic loss due to the radial diffusion was negligible in this measurement.

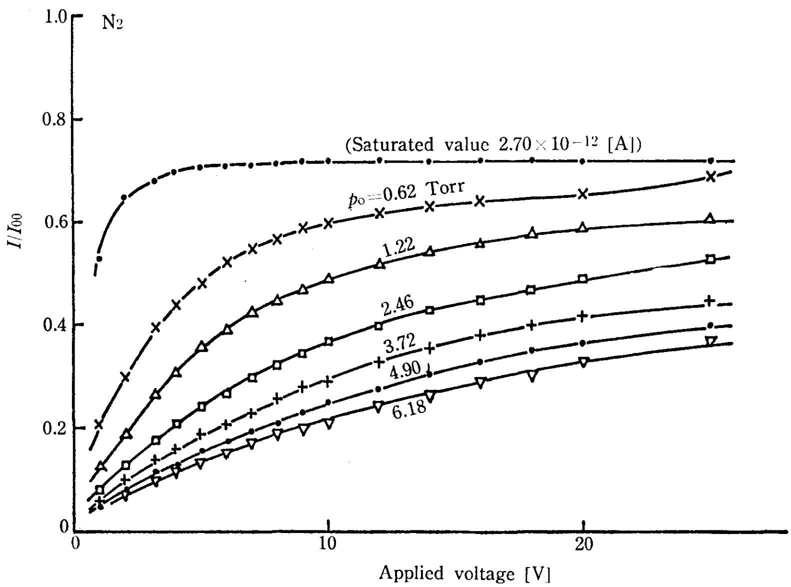

Fig. 4. An example of the V-I characteristic in nitrogen (d=0.6 cm)

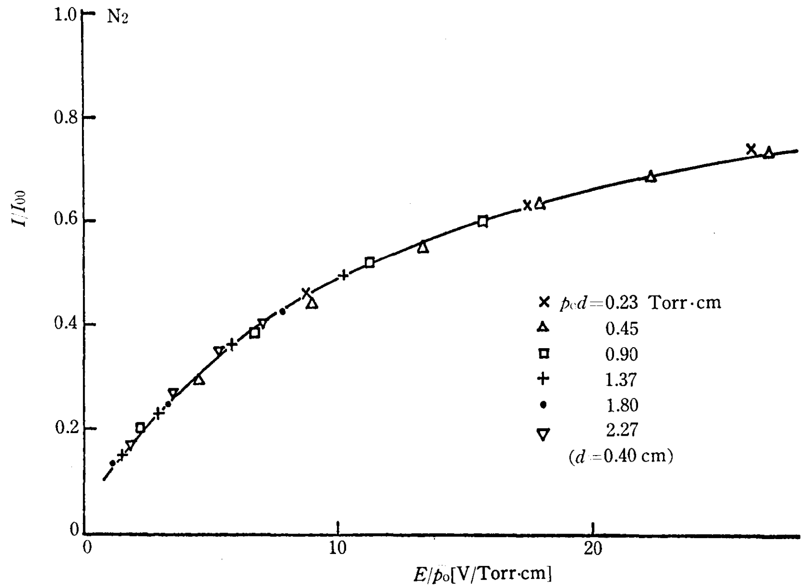

Fig. 5. The normalized current against E/p_0 (d=0.40 cm)

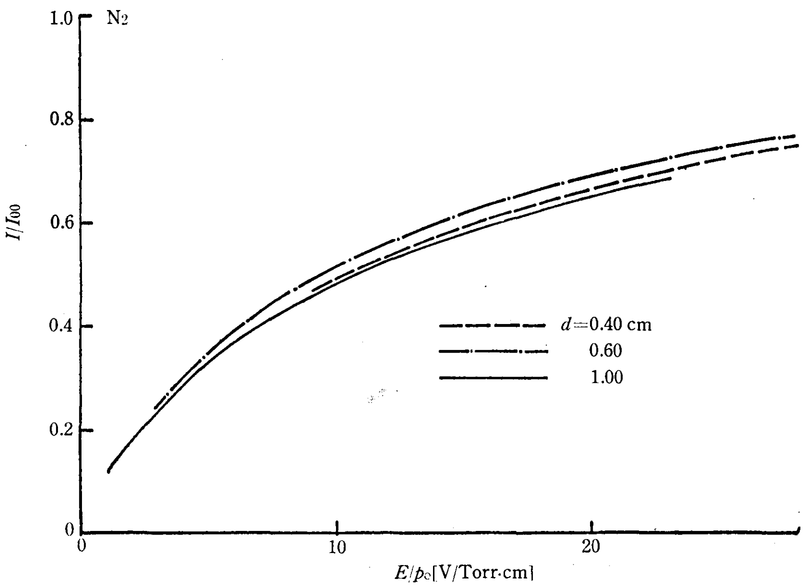

Fig. 6. The normalized current against E/p_0 in N_2 for various gap separation

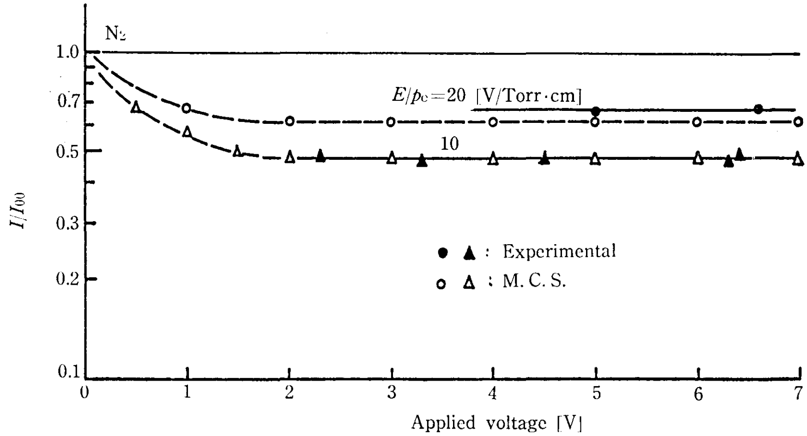

Fig. 7. The normalized current against the applied voltage at constant E/p_0s (nitrogen, $d=0.40$ cm)

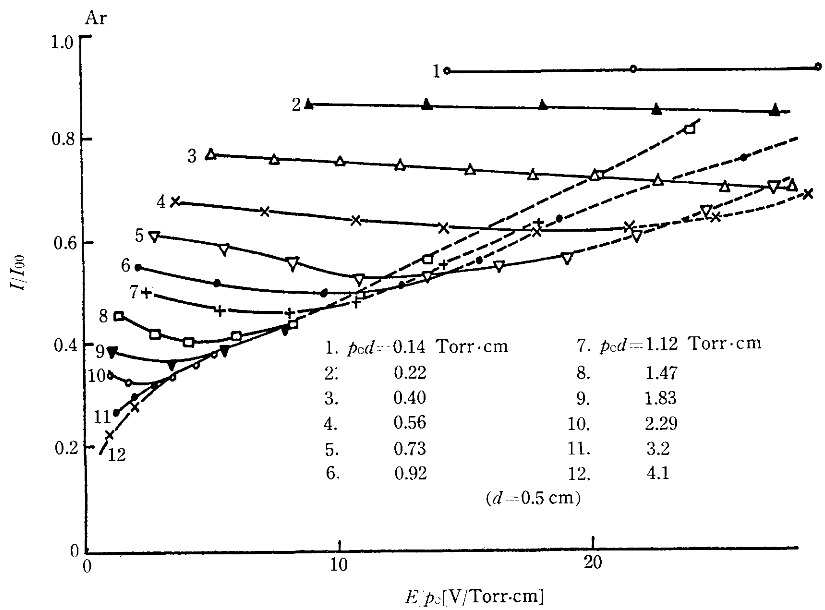

Fig. 8. The normalized current against E/p_0.

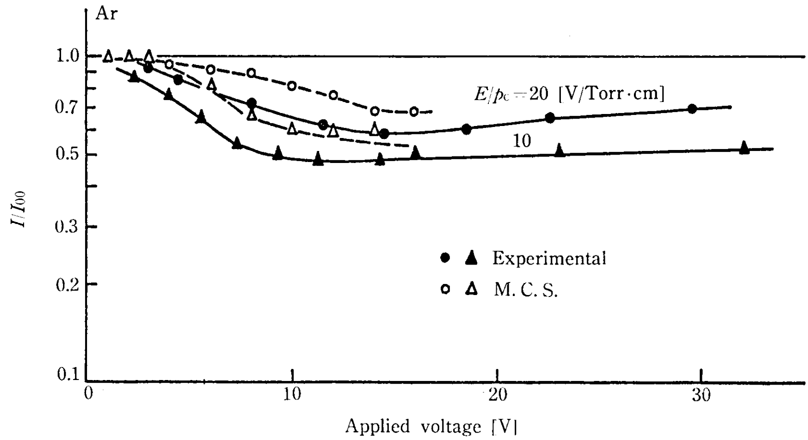

Fig. 9. The normalized current against the applied voltage at constant E/P_0s.

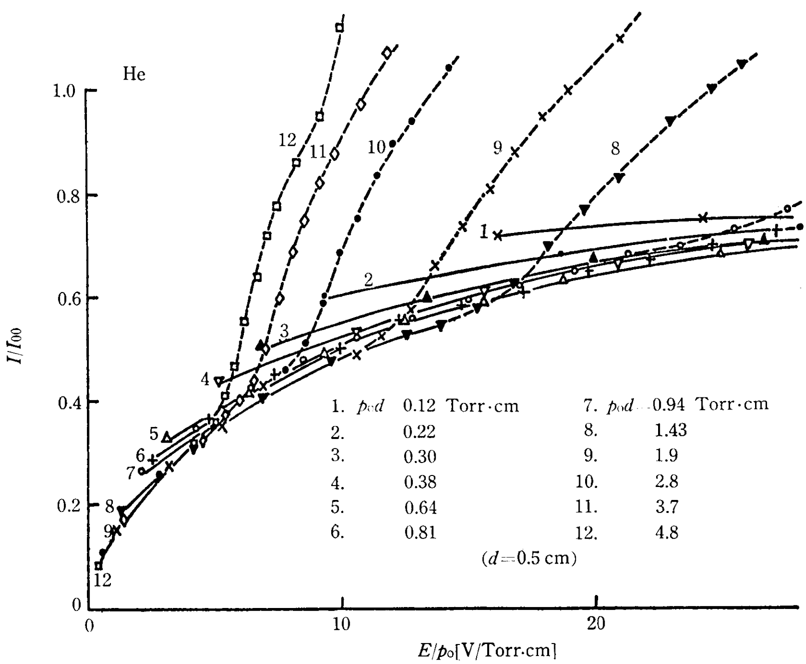

Fig. 10. The normalized current against E/P_0.

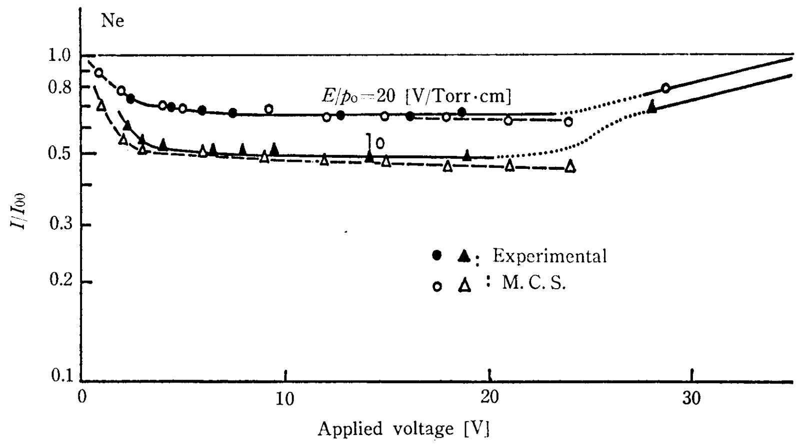

Fig. 11. The normalized current againt the applied voltage at constant E/P_0s.

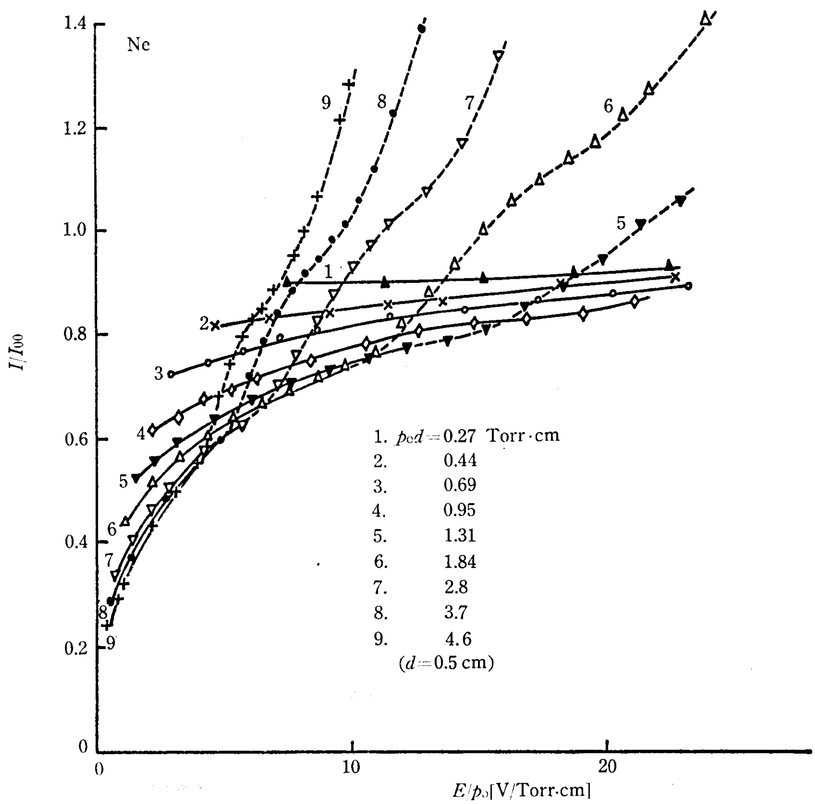

Fig. 12. The normalized current against E/P_0.

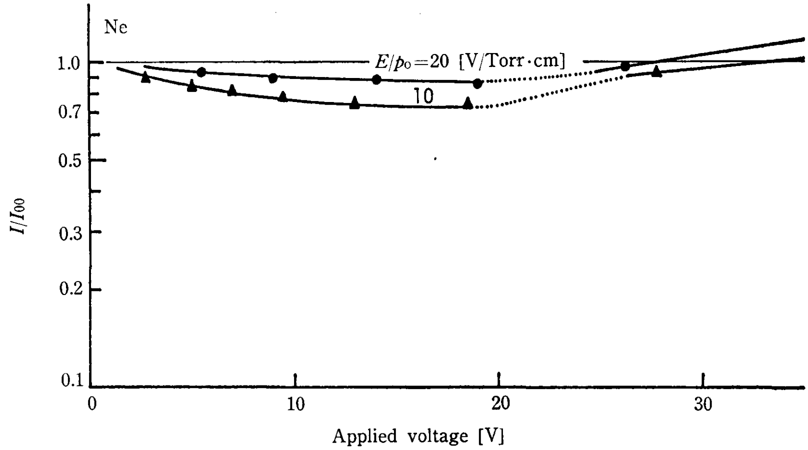

Fig. 13. The normalized current against the applied voltage at constant E/p_0s.

Because the radial diffusion loss of electrons can be ignored, the decreases of the normalized currents in Figs. 7, 9, 11 and 13 could be explained only by the scattering of electron back to the cathode, that is, by the back scattering of electrons.

(2) Results of the Monte Carlo simulation

Ratio of the number of electrons released from the cathode to that of the electrons being able to arrive at the anode was calculated by the Monte Carlo simulation in nitrogen, argon and helium. The method of the simulation was, in principle, the same as the references[4][5]. The initial energy of electrons was assumed to be 0.2 eV, and 50 trials were carried out at each point.

The results of the calculation are shown in Figs. 7, 9 and 11 by blank marks, and coincide with that of the experiments is fairly well.

4. Discussion and conclusions

The characteristic of photo-electronic current in low pressure gas under the influence of low accelerating field can be understood as follows from the foregoing results.

No equilibrium between electrons, gas and field is attained in this region, so that any theoretical formalism is quite difficult.

(1) The effect of back-scattering

Decreases of the normalized current in increasing the applied voltage, which is equivalent to increasing the product $p_0 \cdot d$ at a constant E/p_0, can only be explained by the back-scattering of electrons released from the cathode because the radial diffusion of electron is negligible here.

A simple kinematic consideration shows that electrons released from the cathode with relatively small kinetic energy, e_0, can again arrive at the cathode unless they spend their energy more than e_0 in colliding with gas atoms. After electrons travel an appropriate distance from the cathode and acquire an adequate amount of energy they can collide with gas atoms inelastically and consume the corresponding amount of energy. If the energy loss in collision is greater than e_0, the electron cannot arrive at the cathode any more.

The distance x, within which the back-scattering of electrons can take place, is determined by the equation,

$$eE \cdot x + e_0 < V_{ex},$$

where V_{ex} represents the threshold energy of the lowest inelastic collision, that is, the lowest electronic excitation of rare gases and the vibrational excitations of nitrogen.

Decrease of the normalized current in neon and argon continued until the applied voltage became 16 and 12 volts, respectively, and the normalized current in nitrogen ceased to decrease before the applied voltage became 2 volts.

(2) The effect of the momentum transfer cross-sections

As shown in Fig. 2 the momentum transfer cross-section of neon and argon increases and that of helium decreases as the incident energy of electron increases. The energy of electron in gas under a uniform electric field increases proportionally as the electron leaves far apart from the cathode as long as it collides with atoms elastically.

Thus the further the electron leaves from the cathode, " the larger atoms " it collides with in neon and argon and " the smaller atoms " in helium. The energy dependence of the momentum transfer cross-section, therefore, may yield a kind of longitudinal diffusion of electrons, backward diffusion in neon and argon and forward diffusion in helium. The forward diffusion in helium may suppress back-scattering of electron and this can explain that the normalized current in helium ceases to decrease at lower applied voltage than in neon and argon.

(3) Electrons contributing to the ionizing multiplication

Electrons which are able to escape from the back-scattering can only contribute to the following ionizing multiplication and the current corresponding to these electrons can be determined from the minimum of the normalized current at each E/p_0.

On begining ionizing collision the current starts to increase, but electrons must travel a little more distance before they begin an equilibrium ionization. The Townsend equation with constant parameters can describe the phenomena with an equilibrium ionization[6].

An effect of non-equilibrium ionization will not be mentioned here though the experiment about the effect of non-equilibrium ionization has been completed.

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