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Energy Spectrum of Ions Obtained in a Glow Discharge with a Cylindrical Cathode

Widmo energetycznych jonów uzyskiwanych z wyładowania jarzeniowego z cylindryczną katodą

Энергетический спектр ионов получаемых из газового разряда с цилиндрическим катодом

INTRODUCTION

The aim of the work was to investigate the energy spectra of ions produced in a glow discharge with the use of a cylindrical cathode.

Earlier investigations carried out by Pahl and Kleimann [3] for several gases have shown an almost 100 per cent energetic homogeneity of the ionic beam. These authors investigated the spectra of the hydrogen, nitrogen, and neon ions; it seemed purposeful to carry out experiments with other gases and to elucidate the role of the accelerating voltage for the optimal conditions of energetic homogeneity.

Pahl and Kleimann used a metal apparatus; the authors of the present work employed a glass apparatus so that the shape of certain electrodes had to be changed.

APPARATUS AND CONDITIONS OF EXPERIMENTS

The apparatus consisted of a glass vacuum tube, divided into three chambers (discharge chamber I, acceleration chamber II, chamber of measurements III) which contained a system of electrodes. The tube

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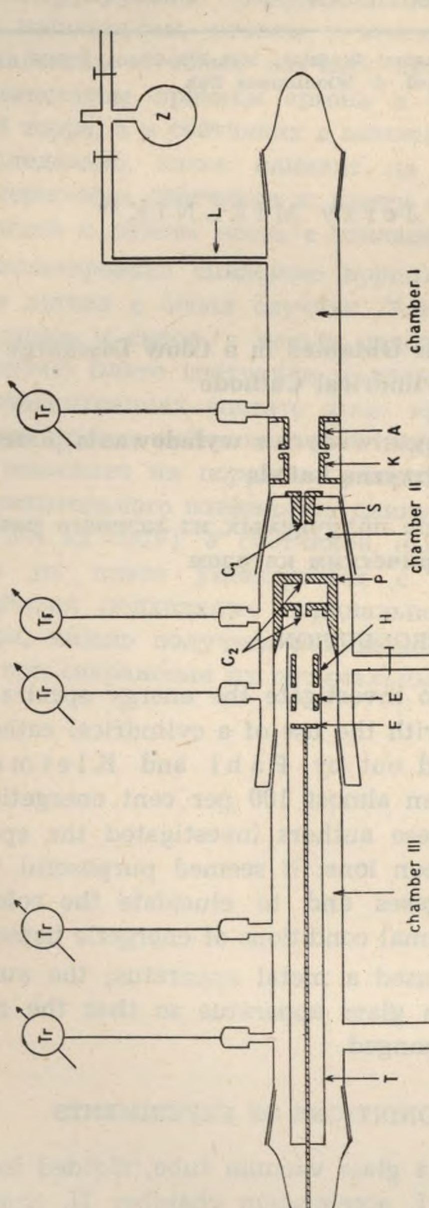

Fig. 1. General design of the apparatus

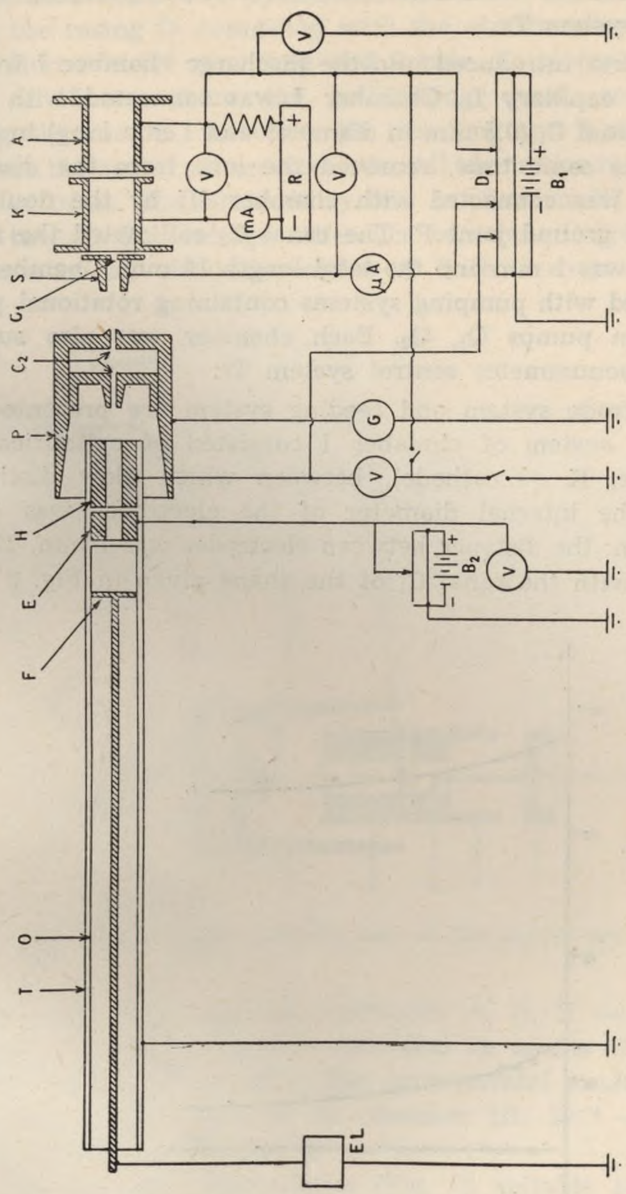

Fig. 2. Schematic diagram of the electrode and feeding systems

was connected to a system of vacuum pumps $P_{1,2}$, $Q_{1,2}$ and to the feeding, measurement, and control systems.

In Fig. 1 the design of the apparatus is presented, with a system of three chambers with electrodes inside, the pumping systems and the control system Tr.

The gas was introduced into the discharge chamber I from vessel Z through the capillary L. Chamber I was connected with chamber II by a small canal C_1 (0.5 mm in diameter and 1 mm long) in diaphragm S which, at the same time, removed the ions from the discharge area. Chamber II was connected with chamber III by the double canal C_2 in the metal ground joint P. The canal C_2 collimated the ionic beams; its diameter was 1 mm and the total length 10 mm. Chambers III and II were supplied with pumping systems containing rotational pumps P_1, P_2 and diffusion pumps Q_1, Q_2. Each chamber was also supplied with a suitable vacuummeter control system Tr.

The electrode system and feeding system are presented in Fig. 2. The electric system of chamber I consisted of cylindrical electrodes (A — anode, K — cathode), between which glow discharges were produced. The internal diameter of the electrodes was 18 mm, the length 24 mm; the distance between electrodes was 1 mm. The removing electrode S with the canal C_1 of the shape given in Fig. 2 was located

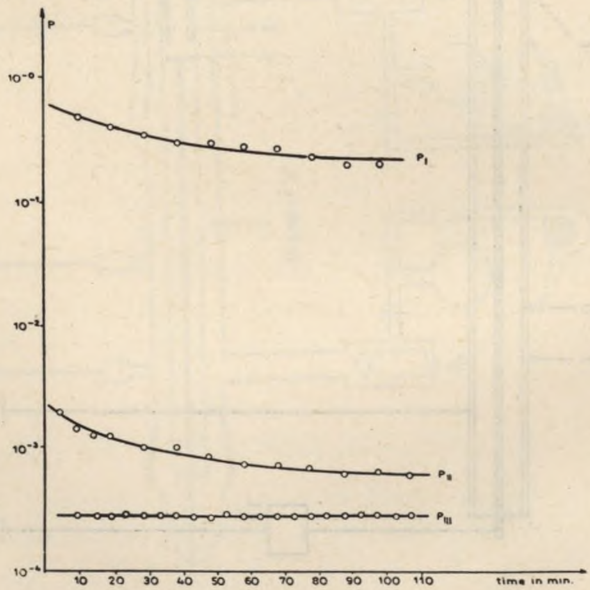

Fig. 3. Vacuum characteristics of the apparatus p_I — pressure in the chamber I, p_{II} — pressure in the chamber II, p_{III} — pressure in the chamber III

at a distance 2 mm from the cathode. The ions were accelerated in chamber II between the electrodes S and P. The electrode P was always earthed during the experiments; inside it had the collimating canal C_2. Chamber III contained two cylindrical electrodes H, E and the collector F in the casing O, connected with the electrometer El. The first cylindrical electrode (20 mm long and 9 mm of internal diameter) at a distance of 15 mm from the collimating canal, constituted the decelerating electrode H, the other (10 mm long and 9 mm of internal diameter) was the antidynatron electrode. All electrodes in the apparatus were made of brass. The electrode system in chamber III was screened by an iron tube T. The voltage difference between electrodes A and K was produced by an electron rectifier R with a controlled potential

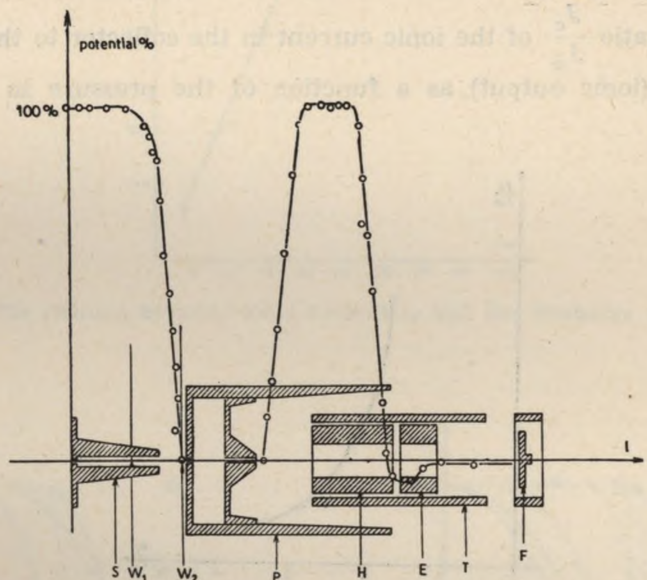

Fig. 4. Distribution of potential along the axis of the second and third chambers

range of 0—500 V, and between electrodes A, S, H — by an anode battery B_1; the latter voltage was controlled by means of an electronic divider in the range of 0—1000 V. The experimental conditions required pressures of the order: 10^{-4} Tr in chamber III, 10^{-4} — 10^{-3} Tr in chamber II, 10^{-1} Tr in chamber I.

From the vacuum characteristics (Fig. 3) suitable pressures were chosen in the corresponding chambers, for the pumping systems in action and for the gas introduced simultaneously into chamber I.

In order to estimate the conditions of acceleration and deceleration of ions the distribution of potential was examined along the axis 1 of the tube, from electrode S to collector F (Fig. 4), by the electrolytic tank method [4].

During measurements the electrodes S and H had the same potential. The ratio of the potential to that of electrode E was 700 : 30. It can be seen from the diagram that the decelerating potential was equal to the potential of electrode H. The ions were accelerated at a distance of W_1 W_2 equal to ca. 10 mm.

The glow discharge was produced at gas pressures of $5 . 10^{-1}$ — $1.7 . 10^{-1}$ Tr and voltages of 380—400 V. Under these contidions the whole area of discharge was occupied by negative glow. In order to investigate the conditions of the glow discharge the following characteristics were determined:

1. The ratio $\frac{J_c}{J_w}$ of the ionic current in the collector to the discharge current I_w (ionic output) as a function of the pressure in chamber I (Fig. 5).

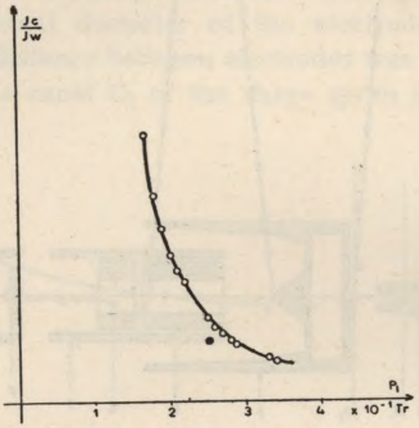

Fig. 5. Ionic output as a function of pressure in chamber I

The characteristic was determined at accelerating voltage U_{SP} between the electrodes S and P equal to 500 V. Electrodes A and S possessed the same potential 500 V. It can be seen from the diagram in Fig. 5 that the ionic output increases markedly with decreasing pressure in the discharge chamber.

2. The ionic current I_c in the collector as a function of the discharge current (Fig. 6).

The characteristic was determined under the following conditions: voltage U_{SP} = 500 V, electrodes A and S had the same potential 500 V,

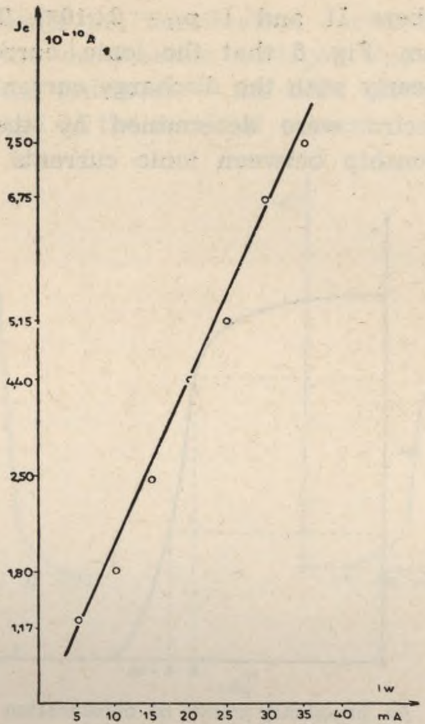

Fig. 6. The relation between ionic current I_c and the discharge current I_w

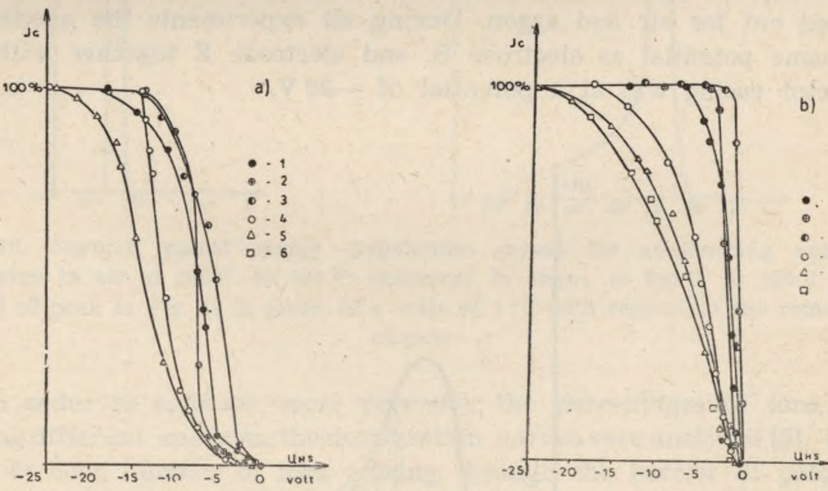

Fig. 7. Experimental decelerating curves for different acceleration voltages: 1 — 100 V, 2 — 200 V, 3 — 300 V, 4 — 400 V, 5 — 500 V, 6 — 600 V, a) discharge in air, b) discharge in argon

pressures in chambers II and I $p_{II} = 2 \cdot 10^{-3}$ Tr, $p_I = 5 \cdot 10^{-1}$ Tr. It can be seen from Fig. 6 that the ionic current in the collector increases almost linearly with the discharge current.

The energy spectra were determined by the decelerating field method. The relationship between ionic currents I_c and decelerating

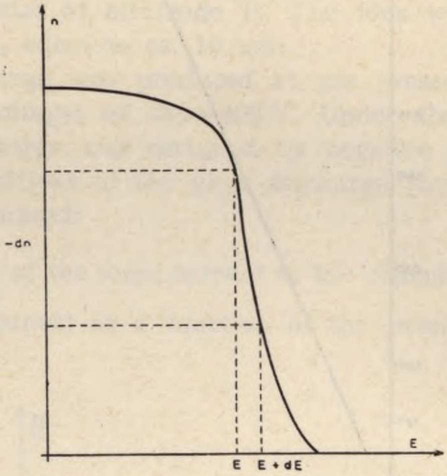

Fig. 8. An imaginary curve of deceleration of ions

potential U_H was determined by varying the potential of electrode H while other conditions remained constant. The measurements were carried out for air and argon. During all experiments the anode had the same potential as electrode S, and electrode E together with the collector casing was at a potential of —30 V.

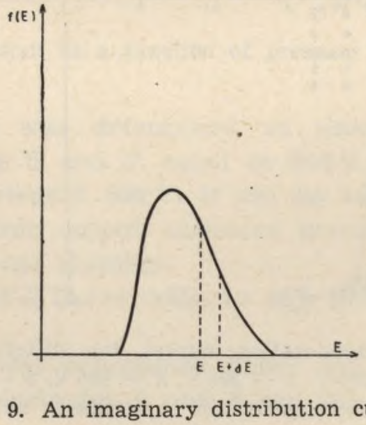

Fig. 9. An imaginary distribution curve

Figure 7a, b presents the deceleration curves for air and argon. The abscissa gives the deceleration voltages U_{HS} measured between electrodes H and S; the ordinates — the ionic current in the collector, expressed in percentage of the maximal current.

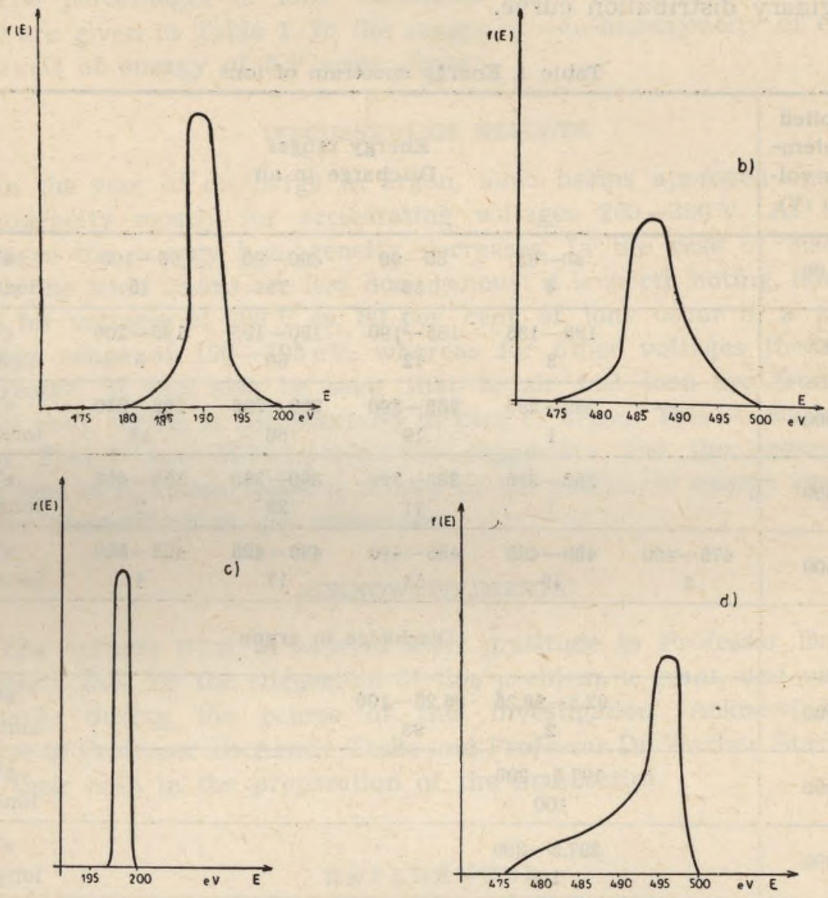

Fig. 10. Several typical energy distribution curves for accelerating voltages. Discharge in air a) 200 V, b) 500 V; discharge in argon, c) 200 V, d) 500 V. (The height of peak in Fig. 10 is given in a scale of 1 : 3 with respect to the remaining curves)

In order to estimate more precisely the percentages of ions possessing different energies, the deceleration curves vere analysed [5]. Let n (Fig. 8) be a number of ions passing through the barrier of potential within the electrode H, then $-dn$ denotes the decrease of the number of ions passed through when the decelerating potential increases from U to $U + dU$. By graphical differentiating of the function of deceleration with respect to the energy eU (or, shorter, E) the relationship $-dn = -n\ (E)\,.\,dE$ is obtained. Introducing new symbols $dN = -dn$, $n'\ (E) = f\,(E)$ we may write $dN = f\,(E)\,.\,dE$ where f (E) is the distribution function of the energy of ions. This is illustrated in Fig. 9 for an imaginary distribution curve.

Table 1. Energy spectrum of ions

Applied acceleration voltage (V)	Energy ranges Discharge in air					
100		80—85 4	85—90 16	90—95 75	95—100 15	eV ions %
200		180—185 3	185—190 12	190—195 80	195—200 5	eV ions %
300		280—285 1	285—290 19	290—295 66	295—300 14	eV ions %
400		380—385 1	385—390 71	390—395 28	395—400 2	eV ions %
500	475—480 2	480—485 19	485—490 58	490—495 17	495—500 4	eV ions %
	Discharge in argon					
100		92.5—96,25 2	96.25—100 98			eV ions %
200		197.5—200 100				eV ions %
300		297.5—300 100				eV ions %
400		380—385 6	385—390 17	390—395 31	395—400 46	eV ions %
500	475—480 5	480—485 11	485—490 16	490—495 50	495—500 18	eV ions %
600	575—580 4	580—585 6	585—590 12	590—595 19	595—600 59	eV ions %

The area of the rectangle of the basis $\triangle E$ in the diagram of the distribution function is proportional to the number of ions N whose energy range is $(E, E + \triangle E)$. The ratio of the surface of the rectangle to the total area between the distribution curve and the abscissa axis gives the fraction of ions which have energies in the range chosen.

The energy distribution curves for several deceleration curves are given in Fig. 10.

The percentages of ions, calculated from the distribution curves *f(E)* are given in Table 1. In the ranges of non-homogeneity of energy intervals of energy of 5 V were chosen.

DISCUSSION OF RESULTS

In the case of discharge in argon, ionic beams approach energetic homogeneity mostly for accelarating voltages 200—300 V. At higher voltages the energy homogeneity decreases. In the case of discharge in air the ionic beams are less homogenous; it is worth noting, however, that for voltages of 200 V ca. 80 per cent of ions occur in a narrow energy range of 190—195 eV, whereas for other voltages the spread is greater. It can also be seen that in air fast ions are from 2 to 5 per cent, which is not observed in case of argon. This seems to confirm Pahl and Kleinmann's suggestion that the presence of fast ions in bi-atomic gases is caused by the additional energy produced at the dissociation of gas molecules.

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STRESZCZENIE

Przeprowadzono badania wyładowania jarzeniowego w powietrzu i argonie z elektrodami cylindrycznymi. Stosując metodę przeciwpola wyznaczono widma energetyczne uzyskiwanych wiązek jonowych. Praca zawiera analizę krzywych hamowania dla potencjałów przyspieszających rzędu kilkuset volt i określa warunki uzyskiwania najbardziej monoenergetycznych wiązek jonowych.

РЕЗЮМЕ

Произведены опыты по газовому разряду в воздухе и аргоне с применением цилиндрических электродов. Методом задерживающего потенциала определялись энергетические спектры полученных ионных пучков. Дан анализ кривых торможения для ускоряющих потенциалов порядка нескольких сотен вольт и определены оптимальные условия моноэнергетических ионных пучков.

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