

INVESTIGATION OF HIGH CURRENT PULSE DISCHARGES IN CONICAL CHAMBERS

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Submitted to JETP editor August 26, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 717-726 (March, 1959)

Some general considerations are presented concerning the possibility of formation of a cumulative jet in the course of contraction of a conical plasma envelope. Preliminary results of some experiments performed with so-called single and double conical systems are presented. Photographs of discharges in conical chambers are presented, and also results of some other measurements.

1. INTRODUCTION

THE present work represents an attempt of utilizing the effect of formation of a cumulative jet as a mechanism of communicating additional energy to a certain group of particles in the course of formation of a plasma column in the process of development of a high current pulse discharge in a gas. The principle on which the investigations that we have carried out is based is similar to the principle of jet formation in a cumulative charge.¹

We shall show that in the process of compression of a gas column of conical shape a jet may also be formed. We consider a conical vessel filled with gas (Fig. 1) through which a rapidly growing current passes. The magnetic forces of the current will compress the gas towards the center of the vessel. In the case of interest to us, when the speed of compression exceeds the speed of sound in the gas, a shock wave is formed moving towards the axis of the vessel. The instant of arrival of the shock wave on the axis (the instant of "singularity") may be determined from the following formula²

$$t_s = 1.8 r \left(\frac{1}{c} \frac{dJ}{dt} \right)^{-1/2} \left(\frac{\pi}{3} Mn \right)^{1/4}. \quad (1)$$

Here Mn is the mass of gas per cm^3 , while $r = r_0 + z \tan \alpha_0$. Evidently t_s will be different at different heights within the vessel. If we make the quite rough assumption that dJ/dt is constant, then the speed of displacement of the point z_1 vertically and the total compression time will respectively be equal to

$$\frac{dz}{dt} = 0.56 \cot \alpha_0 \left(\frac{1}{c} \frac{dJ}{dt} \right)^{1/2} \left(\frac{\pi}{3} Mn \right)^{-1/4}, \quad (2)$$

$$\Delta t = 1.8 l \tan \alpha_0 \left(\frac{1}{c} \frac{dJ}{dt} \right)^{-1/2} \left(\frac{\pi}{3} Mn \right)^{1/4}, \quad (3)$$

i.e., the compression of plasma will be spread

out in time and all the quantities characterizing the process (current, voltage between the electrodes) will vary smoothly.

We consider an intermediate stage of the process of compression (cf. Fig. 1). We assume that at a certain instant of time the front of the shock wave has reached the axis of the chamber at the point z_1 , while above this point the wavefront forms a cone whose vertical half angle is equal to α . The gas contained within this cone may be regarded as unperturbed. We shall at first assume that a strong skin effect exists and the magnetic field does not penetrate inside the plasma. Since the pressure in the compressed column is many times greater than the pressure of the unperturbed gas, then at this instant of time large pressure gradients exist in the plasma, with the maximum value being exhibited by the pressure gradient directed along the axis of the cone. As a result a jet of gas will be propagated along the z axis towards the unperturbed gas, which is analogous to a certain extent to the effect of formation of a cumulative jet.

A consistent solution of the problem encounters a number of mathematical difficulties which have not yet been overcome. A rough estimate of the speed of the jet may be obtained if we make use of the results of the solution of the problem on the propagation of a front of a nonstationary rarefaction wave which arises in the case of an instantaneous removal of a barrier which separates a gas from a region of complete vacuum.³ The speed of the front of the rarefaction wave $v_f = 2u_0/(\gamma - 1)$ or, in the case of a monatomic gas, when $\gamma = c_p/c_v = 5/3$,

$$v_f = 3u_0, \quad (4)$$

where u_0 is the velocity of sound in the gas prior to the removal of the barrier (since the thermal velocity of the gas atoms $v_{T_0} = (3/\sqrt{5})u_0$, then $v_f = 2.2v_{T_0}$).

If we assume that the gas jet represents a rarefaction wave, while the angle α determines only the mass of gas captured into this wave, and thereby the total momentum of the gas jet, then the energy of the particles at the front of jet with respect to a stationary system of coordinates will be several times greater than the thermal energy of the particles in the compressed plasma.*

Such is the rough qualitative picture of this phenomenon in the case of a strong skin effect. However, if the skin effect is weak and the magnetic field of the current penetrates inside the plasma, the problem is even more complicated since in this case the motion of the gas will be determined not only by the gradient of the gas pressure, but also by the difference of magnetic pressures.

As an example we consider the one dimensional problem on the propagation of a rarefaction wave in the presence of a frozen-in magnetic field. We assume that within a certain region of space separated from the rest of space by the plane $x = 0$ we have a plasma of density ρ_0 with a frozen-in magnetic field H_0 , whose lines of force are perpendicular to the plane of the diagram (for $x \geq 0$, $\rho = 0$ and $H = 0$). At a certain instant of time the plasma together with the field H starts spreading into the region of positive values of x . Let us determine the velocity of the front of the rarefaction wave.

The intervals of time in which we are interested are such that the conductivity of the plasma may be considered infinite. Then the equations describing the process will differ from the equations of a similar problem in gas dynamics only by the fact that the pressure of the gas p will be replaced by the sum of the pressure p and of the magnetic pressure $H^2/8\pi$, i.e., by the pressure $P = p + H^2/8\pi$. In virtue of the fact that the magnetic field is frozen-in into a perfectly conducting plasma, we have $H/\rho = H_0/\rho_0$. Taking into account the equation of an adiabatic $p/p_0 = (\rho/\rho_0)^\gamma$ (which may also be written in the form $\rho/\rho_0 = (u/u_0)^{2/(\gamma-1)}$, where u is the velocity of sound) we obtain:

$$P = \frac{\rho_0}{\rho_0^\gamma} \rho^\gamma + \frac{H_0^2}{8\pi\rho_0^2} \rho^2,$$

$$\frac{\partial P}{\partial x} = \frac{\partial p}{\partial x} + \frac{\partial (H^2/8\pi)}{\partial x} = [u^2 + w^2 (u/u_0)^{2/(\gamma-1)}] \frac{\partial \rho}{\partial x},$$

where $w = H_0/\sqrt{4\pi\rho_0}$ is the magnetohydrodynamic velocity in the field H_0 . This equation differs from the corresponding equation for $H_0 = 0$ by the fact that in place of u^2 it contains $[u^2 + w^2 (u/u_0)^{2/(\gamma-1)}]$. Therefore the one dimensional self-similar solution³ obtained in the usual gas dynamics $(v - \eta)^2 =$

*Cf. the experimental determination of the optimum value of the angle α in reference 4.

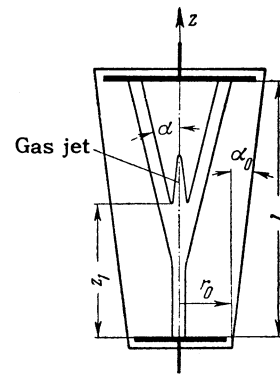


FIG. 1

u^2 (where $\eta = x/t$) must be replaced by the expression

$$(v - \eta)^2 = u^2 + w^2 (u/u_0)^{2/(\gamma-1)}. \tag{5}$$

Further, on utilizing the equation of continuity

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho v)}{\partial x} = \frac{1}{t} \left(-\eta \frac{d\rho}{d\eta} + \frac{d(\rho v)}{d\eta} \right) = 0,$$

we obtain

$$\frac{2}{\gamma-1} \frac{v-\eta}{u} \frac{du}{d\eta} + \frac{dv}{d\eta} = 0. \tag{6}$$

We determine the velocity v by eliminating $v - \eta$ from (5) and (6):

$$v = \mp \frac{2}{\gamma-1} \int \left[1 + \frac{w^2}{c^2} \left(\frac{u}{u_0} \right)^{2/(\gamma-1)} \right]^{1/2} du.$$

On taking into account the fact that in the case of a monatomic gas $\gamma = 5/3$ and $u = (\sqrt{5/3}) v_T$, we obtain:

$$v = \mp 0.83 \frac{v_{T_0}^3}{w^2} \left(1 + 1.8 \frac{w^2}{v_{T_0}^2} v_T \right)^{1/2} + C.$$

Since $v = 0$ when $v_T = v_{T_0}$, we get

$$v = \mp 0.83 \frac{v_{T_0}^3}{w^2} \left[\left(1 + 1.8 \frac{w^2}{v_{T_0}^2} v_T \right)^{1/2} - \left(1 + 1.8 \frac{w^2}{v_{T_0}^2} \right)^{1/2} \right], \tag{7}$$

and at the front of the shock wave where $\rho = 0$, and consequently, also $v_T = 0$,

$$v_f = \mp 0.83 \frac{v_{T_0}^3}{w^2} \left[\left(1 + 1.8 \frac{w^2}{v_{T_0}^2} \right)^{1/2} - 1 \right]. \tag{8}$$

When $w \ll v_{T_0}$ we obtain the already known relation $v_f = 2.2 v_{T_0}$. In the other limiting case when $w \gg v_{T_0}$,

$$v_f = 2w. \tag{9}$$

These results cannot, of course, be directly applied to the case of compression of a conical plasma shell since, first of all, in order to do this a two dimensional problem should be solved, and, secondly, the distribution of gas density and magnetic field in space in our case is no longer uni-

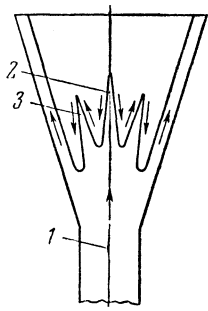


FIG. 2. Probable configuration of currents in the plasma in a discharge in a cone; 1—direction of the main current; 2—gas jet determined by a fall in the gas pressure; 3—gas jet determined by a fall in the magnetic pressure.

form. Nevertheless, we can still draw some qualitative conclusions. On the axis of the vessel where there is no magnetic field the velocity of the front of the jet which will be determined by the fall in gas pressure must be greater, by a factor of 2 or 3, than the thermal velocity of the gas in the compressed column. Nearer to the edge of the column, where the magnetic field increases sharply while the density of particles decreases, a difference of magnetic pressures may prevail and the velocity of the jet at that spot under certain conditions may become greater than the velocity of the jet along the axis (magnetic implosion). Since in this case the moving particles carry the lines of force of the magnetic field along with them the distribution of current over the cross section of the column must change (above the point z_1). As a result of the fact that the total current over the cross section must remain the same local currents may appear in the plasma directed oppositely to the direction of the main current. A possible picture of the distribution of current is shown in Fig. 2.

To increase the energy of interaction of accelerated particles two jets may be created and directed one against the other. Then the distribution of current at a certain instant of time may have the form shown in Fig. 3. Circulating currents flowing within the plasma may lead to the produc-

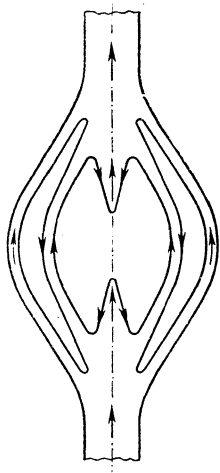


FIG. 3. Probable configuration of currents in the plasma in a discharge in a double cone.

tion of very high local electric and magnetic fields which in turn may communicate to a certain group of particles energy tremendous in comparison with thermal energy.

The possibility is not excluded that such a mechanism of acceleration of a group of particles may be used to explain neutron emission observed in a cylindrical gas discharge at a relatively low plasma temperature. As is well known, the constricting cylindrical plasma column is very inhomogeneous along its length.⁵ One may suppose that the compression of the plasma towards the axis does not take place strictly simultaneously. At some spots the plasma will reach the axis somewhat earlier and other places somewhat later. Because of this at the instant of compression, conical or more complex surfaces may be formed near the axis of the cylinder. As a result when such surfaces contract a cumulative effect similar to the one described above may take place. The fact that the observed neutron emission is localized along certain segments of the compressed plasma⁶ supports this hypothesis. Thus, apparently, it is possible to explain the neutron emission which appears at the instant of the first singularity. A much more intense emission of neutrons at the moment of the next plasma constriction is possibly also due to nonsimultaneous compression. But at this instant along the axis of the tube we no longer have unperturbed gas, as at the instant of the first singularity, but plasma and a magnetic field, and this intensifies the effect of magnetic implosion. It is difficult to indicate the possible configuration of circulating currents at that instant, but it may be supposed that the intensities of the magnetic and the electric fields in such a case may attain very high values.

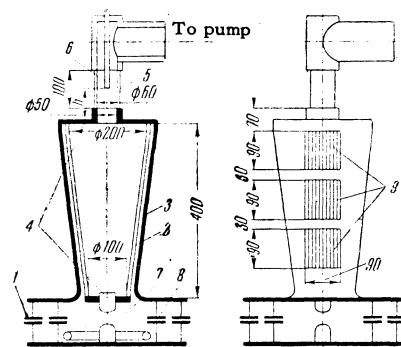


FIG. 4. Diagram of the apparatus. 1—capacitor bank; 2—truncated glass cone; 3—copper coaxial feeder; 4—copper electrodes; in the center of the upper electrode there is an opening of 5 cm diameter; 5—glass cylinder of 6 cm diameter; 6—piezoelectric detector; 7—spark relay; 8—Rogovskiĭ belt; 9—windows in the coaxial line for photographing the discharge.

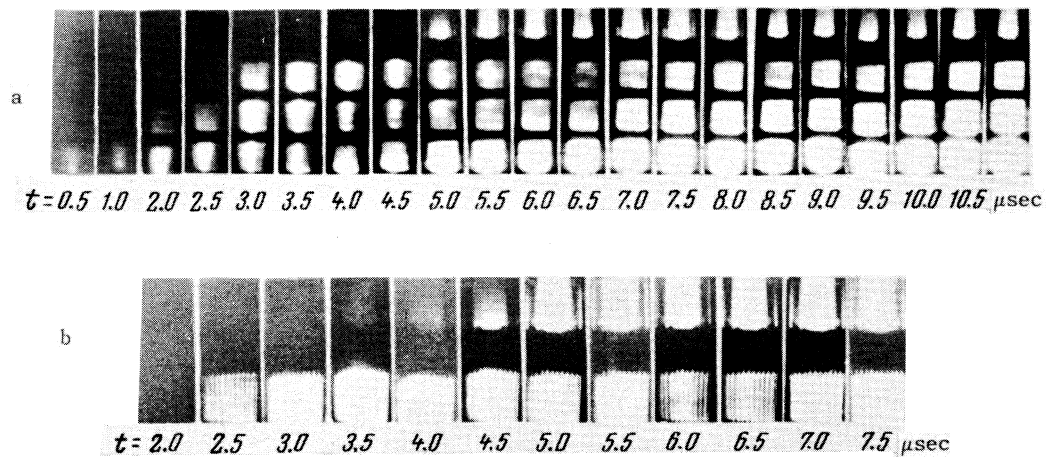


FIG. 5. Photographs of a discharge in deuterium in the conical chamber. $C = 43 \mu\text{f}$, $U_0 = 25 \text{ kv}$, $p_0 = 0.2 \text{ mm Hg}$.

2. INVESTIGATION OF THE DISCHARGE IN SIMPLE CONICAL SYSTEMS

1. The object of the first experiments was to study the process of constriction of plasma in a conical vessel and of the determination of the velocity of its propagation along the axis of the system behind the ring electrode. A schematic cross section of the apparatus and its external appearance are shown in Fig. 4.

The discharge current was measured by means of an integrating Rogovskii belt. For the measurement of the velocity of propagation of plasma behind the upper electrode a piezoelectric detector was used. The use of the piezo effect for the determination of plasma pressure encounters at least two serious difficulties. Firstly, the conditions of the flow around the detector of a pressure wave moving with a speed of more than 10^6 cm/sec are still little known. Apparently the magnitude of the recorded pulse must depend both on the density of the particles in the front of the pressure wave, and also on its velocity. Therefore, there can be no certainty that even relative measurements of the pressure pulse under different conditions give a unique result. Secondly, the absolute calibration of the piezo detector must be performed under the same conditions under which these detectors are used, i.e., at a sufficiently high velocity of the pressure wave. Therefore in the present experiments the piezo detector was used only for the determination of the instant of the beginning of the pressure pulse, i.e., of the instant of arrival of the pressure wave at some specified point in the space behind the upper electrode.

For the investigation of the behavior of plasma in the cone in the initial stages of the discharge an ultra high speed photo recorder (u.h.s.p.r.) was used.⁵ The speed of rotation of the mirror of the u.h.s.p.r. in all cases amounted to 60000 r.p.m. In accordance with this the time interval between frames in all the photographs shown below is equal

to $0.5 \times 10^{-6} \text{ sec}$. In order not to disturb the essentially axial symmetry of the current distribution in the course of photographing the discharge, three openings with conducting covers were made in the coaxial feeder bringing up the current to the discharge gap. Thus in the photograph (cf. Fig. 5a) we can see in each frame four rectangles situated one below the other. The three lower rectangles represent the windows in the coaxial feeder. The upper rectangle is a glass tube placed behind the ring electrode.

The experiments were carried out under the following conditions: the capacitance of the condenser bank which served as the supply for the discharge was $C = 35 - 45 \mu\text{f}$, the initial voltage on the condensers was $U_0 = 25 - 40 \text{ kv}$, and the initial deuterium pressure was $p_0 = 0.02 - 1.0 \text{ mm Hg}$.

2. The photographs of the discharge enable us to obtain some idea about the initial stage of the process. As in the case of a cylindrical chamber breakdown occurs near the walls. Then, as the current increases, the plasma begins to constrict towards the axis of the chamber. From the photograph (Fig. 5) it is seen that constriction of plasma occurs first in the region nearest to the vertex of the cone. With time the region of constriction extends towards the ring electrode. The whole process of compression lasts approximately 1.5 microseconds. However, even when the gas has been compressed only in the central part of the chamber the plasma column near the lower electrode is already beginning to break up. Towards the end of the process of compression when a plasma column can be seen near the ring electrode a compressed column no longer exists in the remainder of the chamber.

Figure 5b shows a photograph of only the upper window in the coaxial cable and the glass tube behind the electrode. The speed of propagation of the luminosity in the tube is approximately equal to $1.1 \times 10^7 \text{ cm/sec}$.



FIG. 6. Photograph of the glass tube beyond the upper electrode of the cylindrical chamber during discharge in deuterium; $C = 43 \mu\text{f}$, $U_0 = 25 \text{ kv}$, $p_0 = 0.2 \text{ mm Hg}$.

Figure 6 gives for comparison a photograph of a similar glass tube placed behind the electrode of a straight discharge tube whose diameter is equal to the diameter of the larger base of the cone (i.e., 20 cm). In this case the speed of propagation of the luminosity is somewhat smaller ($\sim 7 \times 10^6 \text{ cm/sec}$).

3. As already mentioned, the speed of propagation of the gas jet was determined by a piezoelectric detector.⁷ The signal from the detector which was placed on the axis of the cone behind the upper electrode was amplified and applied to the plates of the oscillograph. The signal from the integrating belt was applied to the second pair of plates. Typical curves showing the variation of the discharge current and the pressure are given in Fig. 7. As should have been expected the discharge current varies smoothly. The singularity on the current curve is very much smoothed out. This is in complete accord with the photographs of the discharge which show that the compression of the plasma takes place gradually.

Figure 8 shows the dependence of the instant at which the piezo detector pulse begins on the initial deuterium pressure. The curve was obtained with the distance between the surface of the electrode and the surface of the detector equal to $h = 6.5 \text{ cm}$. The capacitance of the condenser battery in this case amounted to $C = 36 \mu\text{f}$, while the initial voltage was $U_0 = 35 \text{ kv}$ ($J_m \approx 340 \text{ kiloamp}$). The dependence of the instant t_p (at which the pressure

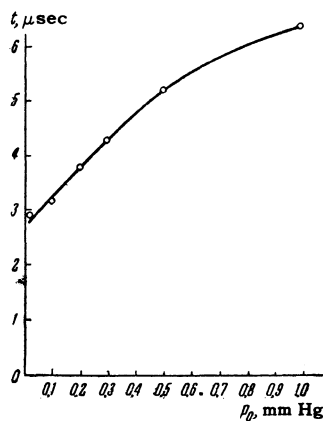


FIG. 8. Dependence of the initial instant of the pulse from the piezodetector on the initial deuterium pressure.

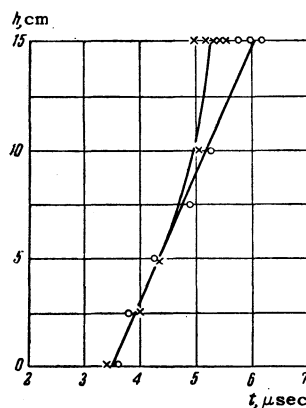
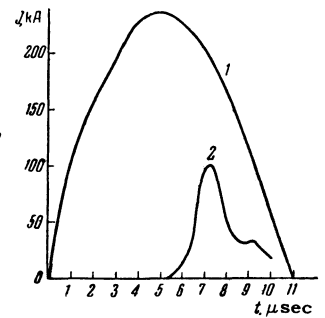


FIG. 9. Position of the front of the gas jet at time t . x - cone, o - cylinder.

FIG. 7. 1—discharge current, 2—pulse from the piezodetector, $C = 35 \mu\text{f}$, $U_0 = 25 \text{ kv}$, $p_0 = 0.2 \text{ mm Hg}$.



pulse begins) on the value of h was obtained at $C = 43 \mu\text{f}$, initial deuterium pressure of $p_0 = 0.3 \text{ mm Hg}$ and at 3 different initial voltages ($U_0 = 25, 30, \text{ and } 38 \text{ kv}$). A common characteristic of all three curves is the fact that initially (as h changes from 0 up to approximately 5–8 cm) t_p varies linearly, but at larger h an appreciable deviation from a straight line occurs. Figure 9 shows this dependence obtained at $U_0 = 30 \text{ kv}$ ($J_m \approx 300 \text{ kiloamp}$). For convenience, the time is plotted along the horizontal axis. For comparison we have plotted in the same graph the form of $h(t_p)$ obtained when the cone was replaced by a cylinder of 20 cm diameter, but with the same initial voltage and deuterium pressure. Each point on the graph has been obtained by averaging the results of several independent measurements. At $h = 15 \text{ cm}$ the results of all the individual measurements are shown. By utilizing this graph it is possible to make an estimate of the speed of propagation of the front of the jet behind the electrode. In the case of the cylinder this velocity amounts to approximately $6 \times 10^6 \text{ cm/sec}$. For the cone the velocity of the front of the jet increases as it moves away from the electrode from $6 \times 10^6 \text{ cm/sec}$ to $\sim (1.5 - 2.0) \times 10^7 \text{ cm/sec}$. An increase in velocity begins when h is of the order of the di-

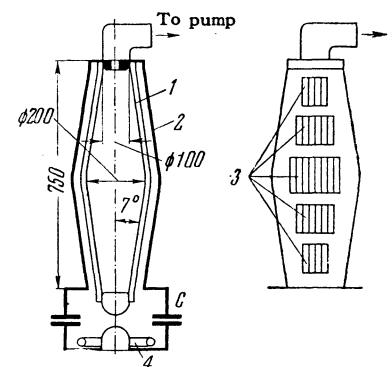


FIG. 10. Diagram of the double conical system. 1—glass chamber; 2—copper coaxial feeder; 3—windows with covers; 4—Rogovskii belt.

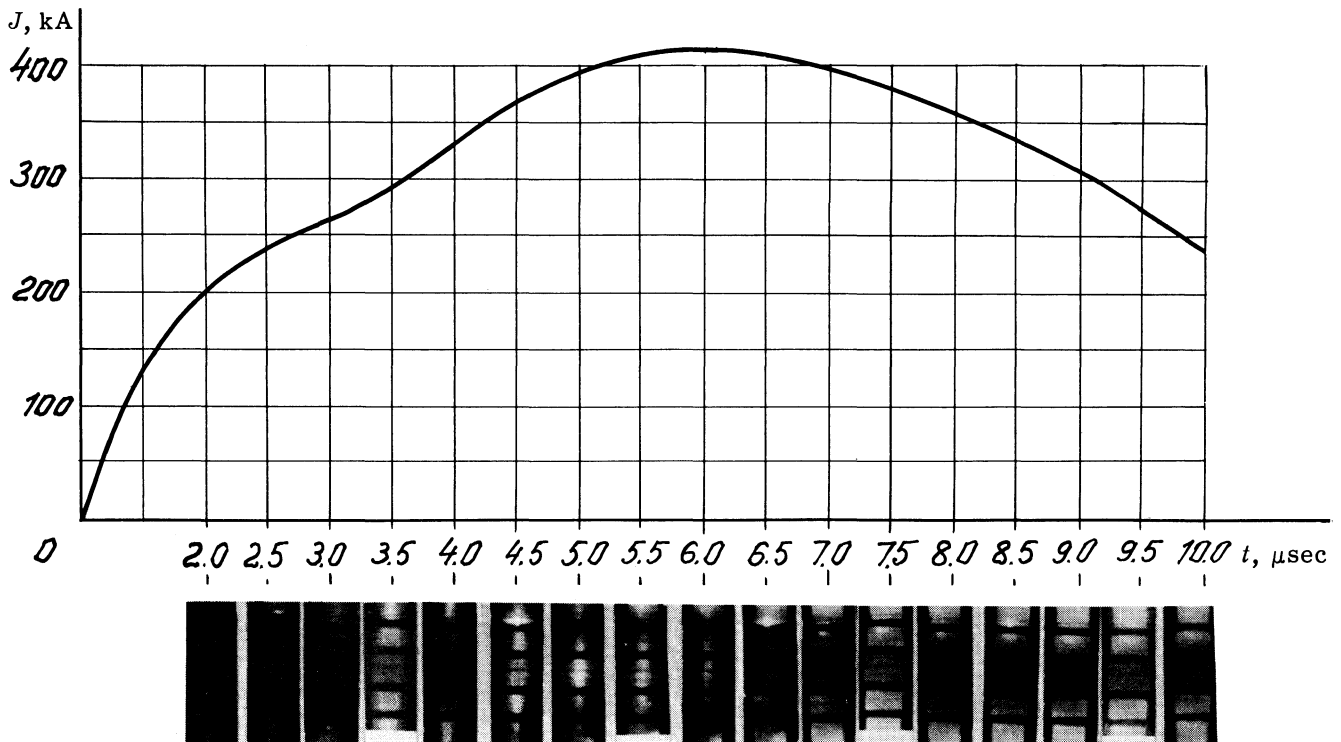


FIG. 11. Photograph and oscillogram of the discharge current in deuterium in a double conical system.

ameter of the opening in the upper electrode. One might conjecture that here apparently some electrode effects are felt as a result of which the jet is no longer formed in the region close to the upper electrode.

3. INVESTIGATION OF THE DISCHARGE IN DOUBLE CONICAL SYSTEMS

1. To use the energy of the particles carried by the gas jet it seems advisable to produce in the same system two jets directed one against the other. A diagram of the simplest apparatus in which such a process may be realized is given in Fig. 10.

A photograph of the discharge in such a system obtained with $C = 43 \mu\text{f}$, $U_0 = 35 \text{ kv}$ ($J_m \approx 410$ kiloamp) and $p_0 = 0.2 \text{ mm Hg}$ is shown in Fig. 11. The following two features should be noted. First, the compression of the plasma begins at the electrodes and extends towards the center of the chamber. This indicates that in such a system two opposing jets may actually be formed. Secondly, the breaking up of the compressed column also begins near the electrodes. The compressed column of plasma in the central part of the system exists for a relatively long time ($\sim 2 \mu\text{sec}$). This may be explained by the fact that when the plasma column near the electrode begins to break up, the inductive reactance of the discharge decreases, the current rises, and the electrodynamic forces compress-

ing the plasma are also increased. Because of this, just in that part of the discharge where the greatest number of particles is available per unit length (and, correspondingly, the density of particles in the constricted plasma column is greatest) and where the energy of the particles is also a maximum, as a result of the formation of the jet, the constricted column lasts for a longer time, than in the case of a discharge in a straight tube under the same conditions.

Figure 12 shows a photograph and an oscillogram of the discharge current in argon, where all the characteristic phenomena are exhibited more distinctly. The photograph was obtained at an initial voltage of $U_0 = 32 \text{ kv}$ ($J_m \approx 350$ kiloamp) and at an initial pressure of $p_0 = 0.05 \text{ mm Hg}$. The plasma column in the central part of the system lasts approximately until the end of the first half period of the discharge current.

2. Some measurements were carried out using a double porcelain cone whose dimensions differed somewhat from the dimensions of the glass cone. The diameter of the larger base of the truncated porcelain cone was 250 mm, the diameter of the smaller base was 90 mm, the height of each cone was 275 mm, the distance between the electrodes was 550 mm, the half-angle at the vertex of the cone was 17° .

Figure 13 shows oscillograms of the discharge current and of the voltage between the electrodes

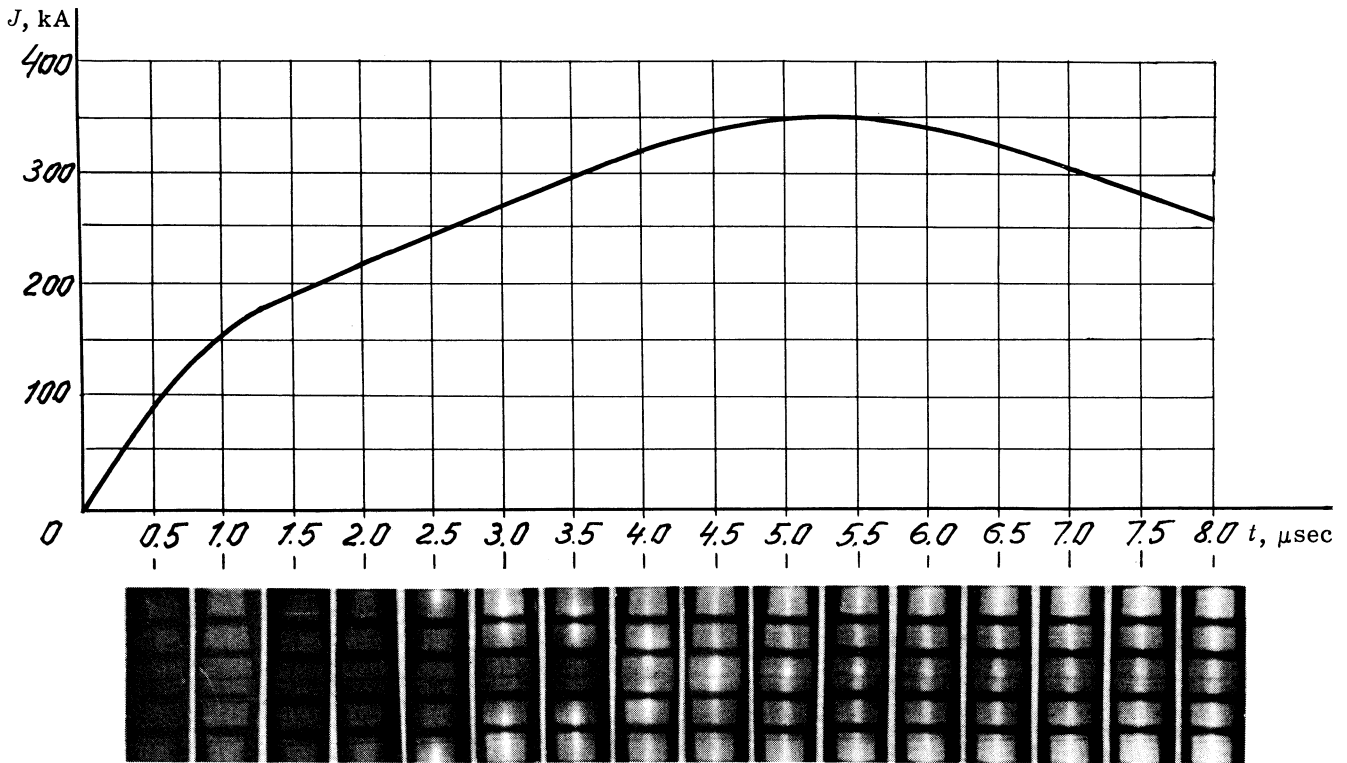


FIG. 12. Photograph and oscillogram of the discharge current in argon in a double conical system.

in the double cone, and for comparison also the same oscillograms obtained for the discharge in a cylinder. While the latter (curves c and d) exhibit three singularities, the oscillogram for the cone (curves a and b) shows only one smooth singularity indicating that the compression of plasma and its decay occur gradually, which is in accord with the photographs of the discharge. This is also confirmed by measurements of the velocity of propagation of the discharge current from the periphery towards the axis of the chamber carried out by means of magnetic probes (cf. Fig. 14).

Two small coils (of cross section 0.4×0.6 cm and with a number of turns $w = 15$) were placed inside the chamber. One of these was placed in the median plane (coil 1) while the other was placed at a distance of 12 cm from the first one in the direction towards the upper electrode

(coil 2). Thus the radius of the first cross section was 12.5 cm, while the radius of the second was 9 cm. Both coils could be displaced radially. Since all the oscillograms were obtained consecutively it is not possible to obtain from these measurements the distribution of the current density over the cross section of the chamber, but the data on the propagation of the current front shown in Fig. 14 may be regarded as sufficiently reliable. Moreover, from the oscillograms obtained it is seen that near the axis of the chamber, in its median cross section, at the time of compression a current exists in a direction opposite to the discharge current. This supports to some extent the hypothesis concerning the existence of closed cir-

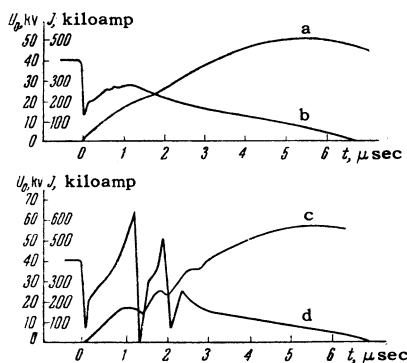


FIG. 13. Oscillograms of the voltage between the electrodes and of the discharge current in the porcelain double cone and in the straight tube. In both cases $C = 65 \mu f$, $U_0 = 40$ kv, $p_0 = 0.06$ mm Hg. (deuterium).

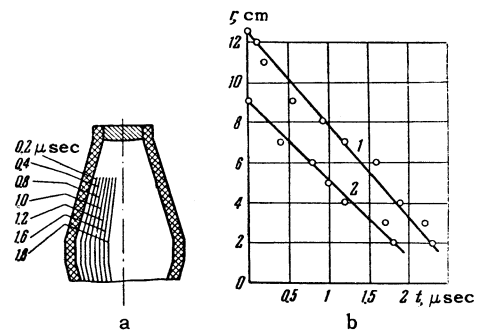


FIG. 14. a—propagation of the current front towards the axis of the system, b—curves showing the compression of the inner boundary of the current towards the axis of the porcelain double cone: 1—magnetic probe No. 1; 2—magnetic probe No. 2.

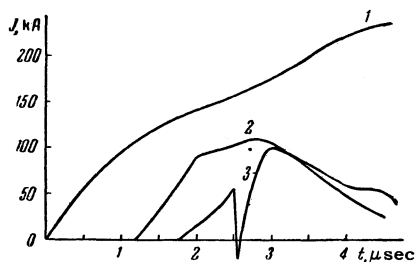


FIG. 15. Current in the region near the axis of the porcelain double cone. 1—total current; 3—current in the middle section of the chamber measured by means of a small coil placed at a distance of 4 cm from the axis; 2—the same current in a section situated 12 cm above the first.

culating currents in the discharges of such a type. The duration of the "reverse" current does not exceed $0.3 \mu\text{sec}$. Figure 15 shows curves of the variation of current recorded by both coils at a distance from the chamber axis of $r_1 = r_2 = 4 \text{ cm}$ (it is assumed that the cylindrical symmetry of current distribution in the initial stage of the discharge is not upset).

3. In the course of all the experiments with the porcelain double cone the neutrons and the x rays was recorded. A scintillation counter with a NaI crystal or naphthalene with anthracene* served as a detector. Experiments were carried out with $C = 65 \mu\text{f}$, $U_0 = 40 \text{ kv}$ ($J_m \approx 500 \text{ kiloamp}$) and at various deuterium or hydrogen pressures.

The neutron radiation appears after several conditioning discharges, with the pulse of this radiation beginning between the singularity and the current maximum (cf. Fig. 16). No hard x rays (which would be capable of penetrating 2.5 cm of porcelain, 0.1 cm of copper, 0.3 cm of lead and an aluminum screen of thickness 0.5 cm) were observed when the discharge chamber was filled with hydrogen.

CONCLUSION

1. The theoretical investigation of the processes occurring during the constriction of a conical plasma envelope of a high current pulse discharge is a very complicated problem which at present has not yet been solved. Nevertheless, the considerations presented in the first section of this paper allow us to postulate that under certain conditions addi-

*The threshold of sensitivity of this counter is not lower than 10^4 neutrons per pulse. Since the sensitivity of another method of recording neutrons (by means of the induced β activity in a silver foil), which is approximately equal to 10^6 neutrons per pulse, turned out to be insufficient to detect the neutrons, the observed yield must lie in the range from 10^4 to 10^6 neutrons per pulse.

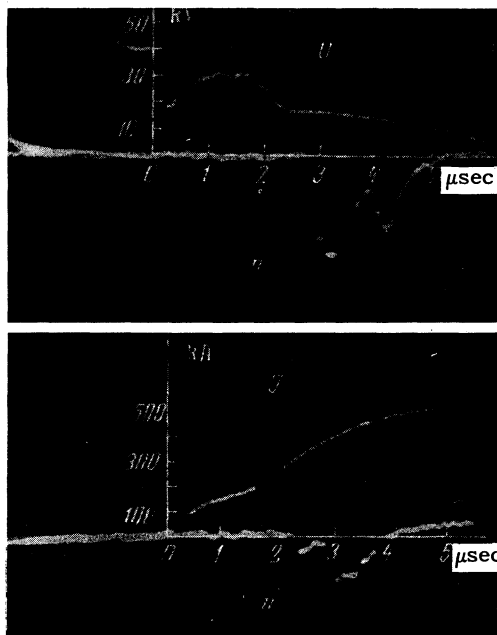


FIG. 16. Oscillogram of the discharge current J , of the voltage between the electrodes U and of the neutron emission n in the case of a discharge in the double conical chamber.

tional energy may be communicated to a certain small group of particles. In particular, in a double conical chamber the temperature of the plasma in the central portion of the column may be increased by these means.

2. Experimental investigations indicate that the cumulative process which occurs in a single conical system leads to a certain increase (by factor of approximately 2 or 3) of the velocity of the plasma along the axis of the column compared to the velocity of the plasma along the axis of a cylindrical system. It should be emphasized that to obtain more accurate and complete information on the motion of plasma in such systems further detailed investigation is required.

3. Investigation of the neutron emission by the plasma produced in a double conical system indicates that this radiation, first, is not related in time to the singularities in the oscillograms of the current and of the voltage and, secondly, is not accompanied by x rays. Unfortunately the experimental data available to us are insufficient to explain either the magnitude of the neutron yield, or the displacement in time between the negative spike of current near the axis (Fig. 15) and the moment of initiation of the neutron pulse.

4. The photographs of Fig. 14 apparently point to a possibility of stabilizing a plasma column by means of prescribing a definite initial configuration of the discharge.

The present work must be regarded only as a

preliminary attempt to study phenomena occurring in the constriction of a conical plasma envelope with the formation of a cumulative jet. To obtain more complete information further theoretical and experimental investigations are necessary.

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Translated by G. Volkoff