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PLASMA PHYSICS AND THE PROBLEM OF THE CONTROLLED THERMONUCLEAR REACTIONS

VOLUME I

PREFACE

The present collection consists of articles in which are presented the theoretical and experimental investigations carried out in 1951-1958 in the Institute of Atomic Energy of the USSR Academy of Science on the problem of the controlled thermonuclear reaction and on the questions of the physics of plasma associated with it. Only those articles which have not been previously published in the press are included in this ~~article~~ collection. The collection is divided into four volumes and the articles are presented generally in chronological order.

The editorial work in this collection was carried out by the candidate of physical mathematical sciences, V. I. Kogan.

Responsible Editor
Academician M. A. Leontovich

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I. E. Tamm: Theory of the Magnetic Thermonuclear Reactor. Part I. (Work completed in 1951); pp. 3-19.

This basic article can be best characterized by giving the headings of the various sections:

(1) The Motion of a Charged Particle in Crossed Fields.

(2) Kinetic Equations. First Approximate Theory (Neglect of Collisions).

(3) Second Approximation of the Theory, the Role of Collisions. Heat Donductivity and Viscosity of the Plasma.

(4) An Orienting Calculation of a Small Model of a Controlled Thermonuclear Reactor with Heating at a Temperature Discontinuity.

A. D. Sakharov: Theory of the Magnetic Thermonuclear Reactor. Part II. (Work carried out in 1951); pp. 20-30.

"The (previous) article by I. E. Tamm presented the properties of the high temperature plasma in a magnetic field and gave hope for realizing the controlled thermonuclear reactor. We are presenting in this article other questions in the theory of the controlled thermonuclear reactor and, in particular:

(1) Thermonuclear reactions Bremmstrahlen.

(2) Calculation of a large model. Critical radius. Boundary phenomena.

(3) The extent of magnetivation. Optimal construction. Productivity with respect to active species.

(4) Drift in ~~an-h~~ a non-homogeneous magnetic field, and increased current. Induction stabilization.

(5) The problem of the instability of the plasma."

The article contains some practical details such as what temperatures and what alloys are going to be used and what the dimensions of the apparatus will be.

I. E. Tamm: Theory of the Magnetic Thermonuclear Reactor. Part III. (Work carried out in 1951);pp. 31-41.

The sub-heading of this article is: "The Drift and Heat Conductivity of the Plasma in a Toroid in the Presence of a Stabilized Current." This work was carried out with the help of N. N. Bogolyubov.

"On the question to which this article is devoted there existed wrong ideas (which I shared, though I expressed them verbally and not in a written form). It was assumed that the drift lines of particles, which differ by either their charge or ~~relationship~~ ratio between parallel and perpendicular components of the velocities with respect to the magnetic field, cross one another and this leads to a sharp increase of heat exchange in a non-uniformly heated plasma (with respect to the case of a straight cylinder). . . . "

In this article, formulae are given which permit one to calculate the heat conductivity as a function of the field of the stabilized current flowing in the plasma and of the field of the windings on the toroid.

A. M. Andrianov, O. A. Bazelevskaya, S. Yu. Luk'yanov, S. M. Osovets, Yu. F. Petrov, I. M. Podgorni, N. A. Yavlinski: Investigation of the Heating of ~~Heated~~ Hydrogen Plasma in Small Toroidal Systems. (Work carried out in 1951); pp. 42-65.

"In the present work the physical basis of the optical and electrical method of measuring some of the parameters of the plasma are described. The experimental set-up is given and also the technique of carrying out the measurements. The more important experimental data are given and the results obtained discussed."

There are 14 diagrams in this article.

G. I. Budker: Questions Associated with the ~~Drief~~ DRIFT Drift of Particles in a Toroidal Magnetic Thermonuclear Reaction. (Work carried out in 1951); pp. 66-76.

"An investigation is made of the ~~dra~~ drift of particles in a non-homogeneous magnetic and electric field. An evaluation is made of the heat conductivity in a toros on stabilization of the ~~dra~~ drift by a magnetic field of a longitudinal current and by some other methods. The considerations presented permit one to conclude concerning the insufficiency of compensation of the drift by weak longitudinal current. An evaluation shows that it is necessary for ~~stabilization~~ STABILIZATION realization of a thermonuclear reaction that the field of the stabilizing current be of the same order of magnitude as that of the basic field. In addition to this, it is necessary to create additional fields associated with the walls of the chamber which would hold the plasma as a whole within the toros.

B. I. Davidov: The Influence of the Vibrations of the Plasma on Its Electrical and Thermal Conductivity. (Work carried out in 1951); pp. 77-88.

"We have evaluated the influence of the vibration to the plasma on the motion of electrons and ions in it and on its heat conductivity assuming that the vibration intensity corresponds to heat equilibrium. It is well known that arbitrary order currents in the plasma lead to an artificial excitation of the vibrations. In addition, their intensities may be considerably greater than that given by the Raleigh-Jeans formula."

B. I. Davidov: Ignition of an Electrodeless Discharge. (Work carried out in 1951); pp.89-94.

After a general discussion of the difference between ignition in a discharge with electrodes and one without electrodes, the author considers the cases of ignition without a circular magnetic field and then one in the presence of a constant longitudinal circular magnetic field.

A. M. Andrianov, and S. M. Osovets: Theory and Experiments on the Ignition of an Electrodeless Discharge in a Magnetic Field. (Work carried out in 1951); pp. 95-109.

The topics in this article are:

(1) Theory of the breakdown in the absence of the magnetic field.

(2) Theory of the breakdown in a toros or in the presence of a longitudinal magnetic field.

(3) Time dependence.

(4) Experiments for studying the breakdown in hydrogen. The work was done

in a glass tube with a diameter of 4 cm bent in form of a toros of a diameter of 50 cm. The electrical field inside the toros is produced by a discharge of 2.5 mkv across a copper coil placed in the middle of the toros. Inside the windings for increasing the connection between the copper windings and the gas windin there was an iron insert with a 150 cm cross section. Tables are given of the results as a function of pressure and potential.

(5) Conclusions show that the experiments agree within 30% of the theory.

M. A. Leontovich: Forces Acting on a Linear Current Which Is within Conducting Cylindrical Tubes. (Work carried out in 1951); pp. 110-114.

"In connection with the question of stabilizing the currents with the help of a conducting tube surrounding it, we have derived several elementary formulae for forces acting on the current."

S. I. Braginski: Compression of a Plasma under the Action of its Own Magnetic Field. (Work - 1951); pp.115-121.

"A passing of a large current through a plasma, ~~of-a-m~~ the magnetic field caused by this current has a strong influence on the motion of the charged particles in the plasma and on the configuration of the whole plasma. The simultaneous action of the elctric field causing the current and the magnetic field caused by this current leads to a 'drift' of the charged particles of both signs inside the heat conducting channel. This drift ' equilibrates' in the stationary state by the diffusion of the particles to the outside across the magnetic field. The result is that the plasma contracts in a more or less narrow pinch in which almost the whole current flows. The so-called pinch effect. ~~Tis~~ This phenomena was previously investigated theoretically by

A. Schluter, Z. Naturforsch., 5a, 72 (1950), Assuming the constancy in radius of the temperature of the plasma.

"In the present article preliminary results are given of the study of the stationary problem of the compression of a plasma in an infinitely long pipe. The plasma is considered completely ionized. The temperature of electrons and ions is assumed to be the same. The external magnetic field is absent. A more detailed investigation also for the non-stationary processes has been carried out by the author subsequently and published in Journal of Experimental and Theoretical Physics, 33, 645, 1957. . . .

"We wish to thank B. I. Davidov for direction of this work."

G. I. Budker: The betatron method of heating plasma to high temperatures. (Work - 1951); pp.122-129.

"A new method of heating the plasma to high temperatures - the so-called betatron method of heating - is based on the fact that on increasing the magnetic field the temperature of the plasma increases. The results are compared with the previously proposed method of heating with the help of a longitudinal electric field. The problem is solved for the first model: an infinite straight tube with a magnetic field directed along the axis.

V. I. Kogan: The velocity of equilibration of the temperatures of charged particles in a plasma. (Work - 1951); pp.130-137.

"Calculations are made in this work of:

(1) The velocity of energy exchange between two degrees of freedom of a gas of charged particles present at one temperature and a third degree of freedom of the same gas present at another temperature (applicable to the problem of the betatron heating of the plasma).

(2) The velocity of equalization of the temperature of chargedparticles of the two types for any ratio of their masses.'

D. N. Zubarev, V. N. Klimov: The Theory of the Temperature Jump at the Boundary of a Plasma in a Magnetic Field. (Work - 1951) pp.138-161.

"The temperature discontinuity has been examined at the boundary of a magnetized plasma with consideration of processes of ionization excitation and charged transfer of atoms in the layer near the walls. . . .

"It is shown that the temperature discontinuity can take place under conditions of the large model of the controlled thermonuclear reactor (the mean free path of neutral particles being small compared to the dimensions of the system) for values of the heat flow to the walls and for density of particles in the center of the system of the order of val magnitude of the technical model. / .

"In conclusion we thank A. G. Sakharov for formulating the problem and taking an active part in its solution."

V. M. Galitski, A.B. Migdal: Dielectric Constant of a High Temperature Magnetized Plasma and the Evaluation of the Radiant Heat Conductivity. (Work - 1951); pp.161-171.

"An expression is found for the dielectric constant of a plasma situated in a magnetic field at high temperatures when there are relativistic effects present. On the basis of the imaginary part of the dielectric constant, an evaluation is made of the radiant thermal conductivity. The radiant thermal conductivity is found to be smaller than the heat conductivity produced by teh particles.

V. I. Kogan, A. B. Migdal: The electron temperature dependence of the spectrum of the Bremmstrahlen of a plasma. (Work - 1951); (and reworked in preparation for publication); pp. 172-177.

"Approximate expressions are derived for the spectral distribution of the intensity of the Bremmstrahlen in its dependence to on the electron temperature of the hydrogen plasma (in the Born and quasi-classical regions of temperature). The possibility is discussed of using these expressions for the determination of the electron temperature using experimental data."

S. I. Braginski: The Flow of Particles and Heat Across a Strong Magnetic Field in a Completely Ionized Two-Temperature Plasma. (Work - 1952); pp.178-185.

"Electron Conductivity of the plasma and the energy flow carried by electrons across the weak magnetic field has been calculated by R. Landshoff, Phys. Rev. 76, 904, (1949). Transverse flow of particles and heat in a strong magnetic field for the same temperatures of ions and electrons has been calculated by Tamm, (page 3). The general transfer equations under these conditions has been obtained by E. S. Fradkin, Journal of Experimental & Theoretical Physics, 32, 1176, 1957. The transfer equations for the case of different temperatures of ions and electrons can be obtained by a method (S. I. Braginski, Journal of Exp. & Th. Physics, 33, 459, 1957) analagous to the method of S. Chapman and T. G. Cowling. The transverse currents in a strong magnetic field for different temperatures of electrons and ions ah has been calculated independently by D. N. Zubarev and V. N. Klimov. Their results correspond with ours.

"We wish to thank B. I. Davidov for the direction of the work and G. I. Budker for valuable discussion."

S. I. Braginski and G. I. Budker: The Physical Phenomena in the Process of the Ignition of a Discharge for Incomplete Ionization. (Work - 1952); pp. 186-206.

"The present article is a preliminary report of the authors on the theoretical investigation of the initial stages of a discharge with a large current in hydrogen. This work was not completed and in the present form contains only the setting up of the problem and an analysis of a series of individual questions but not the solution of the whole problem."

The topics discussed are:

(1) The breakdown and the formation of a quasi-neutral plasma.

(2) The magnetization of electrons and the skin effect.

(3) Forbidden radiation.

M. A. Leontovich, V. D. Shafranov: The Stability of a Flexible Conductor in a Longitudinal Magnetic Field. (Work - 1952); pp. 207-213.

"In this article the problem of the stability of the form of ~~an~~ a non-elastic ~~straight~~ linear conductor of a circular cross section with a current in a longitudinal magnetic field is examined. It is well known that the field of the current produces instabilities with respect to the distortion of the form of the conductor. In the present note it is shown that if the external longitudinal field is sufficiently large, it leads to stability. The minimal value necessary for this field exceeds the value of the field of the current on the ~~limits~~ boundaries of the conductor. The problem is solved with the following assumptions: the conductor is assumed to be ideal and the distortion of the form of the conductor is not large. Under these assumptions it is easy to find a field and a distribution of currents necessary for calculating the forces arising by distorting the conductor."

G. I. Budker: An Electrical Breakdown in a Gas in the Presence of a Strong External Magnetic Field Variable in Time. (Work - 1952); pp.214-221.

"The magnetic field effects (the breakdown) for the most part in three respects: (1) decreases the transverse co-efficient of diffusion; (2) causes the drift of electrons to the center; (3) weakens the transverse conductivity so that the heating of electrons by the induced electric field can be neglected.

"The breakdown is produced by the external longitudinal electric field. In a magnetic field the conditions of the breakdown turn out to be considerably easier than without it, especially in those cases when the magnetic field increases in time. A completely different dependence is found on the density which considerably facilitates the breakdown at small densities. Let us examine the discharge in an infinite straight pipe and in a finite straight pipe. The problem of the discharge in a toros can be resolved to a problem in a straight tube with a sufficiently rapid growing magnetic field."

"M. A. Leontovich: The Magnetic Field of a Linear Current Surrounded by an Ideally Conducting Cylinder with a Cut. (Work - 1952); pp. 222-228.

"The presence of a cut decreases the force near it which pulls the current toward the center of the cylinder."

S. I. Braginski: Investigation of the Axial Region of a Plasma Pinch. (Work - 1952); pp. 229-233).

"Let us considera a homogeneous along the axis cylinder with a completely ionized plasma in which there is a current. The magnetic forces of this current compress the plasma, equilibrating its pressure. Such a pinch for equal temperatures of ions and electrons has been investigated in this volume (page 115).

"It is of interest to investigate what takes place near the axis of the pinch. Close to the very axis where the magnetic field passes through zero the trajectories of the particles have the form of snakes and not circles, as in the other parts of the pinch. Therefore, one can expect here some peculiarities. The necessity of a special study of the region near the axis was first noted by Budker, who showed that at high temperature may be large even inside the region of the snake-like trajectory. We are making an attempt to investigate the region near the axis with the help of microscopic equations. . . .

"I wish to thank B. I. Davidov for the direction of the work and G. I. Budker for useful discussion."

V. S. Komel'kov and V. I. Sinitsin: A Piezo-Electric Method of Investigating a Str~~o~~ong Gas Discharge. (Work - 1952); pp. 234-242.

"In the present work a method is described for the regiati registration of the form and magnetude of pressure pulses passing to the walls of the discharge chamber in the process of development and passage in it of a gass discharge. This method permits the establishment of phase relationships between the discharge current and the pressures on the walls of the chamber and, likewise, for definite assumptions to carry out an evaluation of the energy of the plasma particles. Barium titanate was used as a crystal."

G. I. Budker: Thermonuclear Reaction in a Potential Hole of a Negative Charge. (Work - 1952); pp. 243-248.

"The vk volume filled with electrons represents a potential hole for ions in which, generally speaking, there may be thermonuclear reactions. . . . Unfortunately, electro-magnetic radiation of the electrons is considerably greater than the energy ~~emitted~~ evolved by the reaction. Therefore, in general, such a system is not a reactor with a positive yield of energy.

D. N. Zubarev, V. N. Klimov: Stationary Conditions of a Magnetic Thermonuclear Reactor. (Work - 1952); pp. 249-288.

"An investigation is made of the stationary conditions of a magnetic thermonuclear reactor with consideration of Bremmstrahlen and nuclear reactions in the DD and the DT ~~reaction~~ REACTI. system."

This is a detailed article containing 11 figures, many of them giving results of a large number of calculations. There are also 4 tables, giving the sizes of the calculated nuclear discharges and their conditions of operation.

"We wish to thank I. E. Tamm and A. D. Sakharov, who presented the problem to us. We wish to thank E. N. Golovin, whose important remarks were considered in the final stages of the work. The investigation of the system of euqation is due to A. A. Bunatyan. The calculations were carried out by a brigade of calculators under the direction of the engineer T. V. Vas'kina."

V. A. Trubnikov: The Instability of a Plasma Cylinder. (Work - 1952); pp.289-298.

"The stability conditions of a stationary cylindrical column of a completely ionized gas plasma with a longitudinal current uniformly distributed in cross section is examined. It is shown by a method of small perturbations that the axially symmetrical deformations having a periodic form along the axis of contraction rise exponentially in orders of time $\tau \sim \sqrt{a\lambda_2}/v$ where a is the non-excited radius of a cylinder, λ is the wave length of the perturbation, and v is the heat velocity of the ions. This can lead to a complete disruption of the current in the circuit . . . .

"The present work was carried out under the direct direction of Academician M. A. Leontovich. . . .

"The author also thanks Academician S. L. Sobolev for the organization of the numerical calculations of the problem.

"Note added in proof: In recent times, experimental data were obtained which qualitatively support the picture of the discharge described above. (Private communiation of B. G. Brezhnev.)

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PHYSICS OF PLASMA

AND THE PROBLEM OF CONTROLLED THERMONUCLEAR REACTION

VOLUME II

S. I. Braginski, F. D. Shafranov: The Plasma Pinch with Heat Loss at the Electrodes. (Work - 1953); pp. 3-19.

"In the present article an attempt is made to consider the plasma pinch with electrodes. The presence of electrodes leads to the fact that physical quantities change along the axis in contrast with what must take place in an infinite column as is considered in Volume I, page 178, and Braginski, Journal of Experimental & Theoretical Physics, 33, 459, 1957.

"It is easy to show that in the case when the inertia and the viscosity of the plasma can be neglected and when the proper electric field of the column is small with respect to the magnetic field, the pressure, the current density and the magnetic field in the pinch do not change along the axis.

S. I. Braginski, A. B. Migdal: The Processes in a Plasma Column with Rapid Increase of Current. (Work - 1951)p and partially reworked in preparation for publication in 1956); pp.20-25.

"A short examination is made of the physical processes essential in a powerful pulse discharge; ionization, skin effect, motion of the ions toward the axis and their entrainment of the neutral gas, the convergent shock wave and cumulation of on the axis, the compression of the plasma column with a consideration of the increase of the moving mass, temperature of the ions and of the atoms.

"The experimental investigations of a massive impulse discharge showed that with a rapid increase of the current in a cylindrical discharge chamber a plasma column is formed compressed toward the axis. A qualitative theory of the compression has been developed by M. A. Leontovich and S. N. Osovets (report of the Ac. of Sc., 1953, Atomic Energy 1, 81, 1956), on the basis of a hypothesis of the inertial character of this process. These results of agree well with experiments. The present work is an attempt for a qualitative investigation of the basic phenomena taking place in the process of formation of a plasma column and some refinements of the physical picture of its compression.

S. I. Braginski, V. D. Shafranov: The Plasma Pinch in the Presence of a Longitudinal Magnetic Field. (Work - 1953), pp. 26-80.

"In the present article an investigation is given of the plasma column in the presence of an internal longitudinal field of a magnet. Preliminary presentation is given of the basic results referring to a pinch without a longitudinal field."

The following are the headings of this long article: (1) Equations Describing the Pinch; (2) The Relation of the Pinch to the Temperature; (3) Rapid and Slow Processes; (4) Heat Balance Equations; (5) Change of the Radius of the Pinch with Time; (6) Notes Concerning the Heating of the Plasma and the Compression of the Pinch; (7) A Pinch with Heat Losses; (8) Auto Modeling Conditions; (9) Conditions for Non-Rupture from the Walls; (10) System of Equations in the Presence of a Longitudinal Field; (11) Stationary Case; (12) Rapid Processes; (13) Auto Modeled Conditions; (14) A Pinch Produced by a Longitudinal Field.

L. A. Artsimovich: Passing of Large Currents Through a Plasma in the Presence of a Longitudinal Magnetic Field. (Work - 1953); pp.81-86.

"The question is examined about the behavior of a plasma pinch produced by rather large currents passing through a plasma in the case when the whole system is in a constant field or almost constant field. It is assumed that one can neglect the gas kinetic pressure of the plasma (rapid pulse process). The conductivity of the plasma is considered infinite."

L. A. Artsimovich: Magnetic Current in a Compressing Cylinder. (Work - 1953); pp.87-100.

"Processes are examined in a compressed conducting cylinder present in a magnetic field. Formulae are given for several cases of the change of the cylinder radius as a function of time. In addition to this, an analysis is given of the experimental data and the possibility of determining the conductivity of the cylinder."

L. A. Artsimovich: Analysis of the Equations of the Compression of the Pinch in the Presence of an External Magnetic Field. (Work - 1954); pp. 101-108.

"An analysis is made of the equations describing the compression of a gaseous column in the presence of a constant longitudinal magnetic field. The case is examined when the magnetic time is small compared to the time of the current change and approximate equations are determined for the radius of the pinch."

V. I. Kogan: The Yield of Thermonuclear Reactions. (Work - 1953); pp.109-129.

"The article investigates several questions dealing with the yield of the D.-D. reaction, and in particular: (1) the region of the applicability of the simple analytical expression for the yield (the Bethe-Atkinson formula); (2) the influence of the 'cutting of the tails' of the Maxwellian distribution of ion velocities; (3) the optimum (for a given energy introduced into the system), number of particles for a polytropic law of compression of the reacting plasma; (4) the optimum (for a given current) linear number of particles in a system with a plasma current working with an auto modelling condition (with a consideration of a temperature difference of the ions from the electrons). . . .

"In conclusion, we wish to thank M. A. Leontovich for the discussion of the results."

V. D. Shafranov: Stability of a Plasma Pinch in the Presence of a Longitudinal Magnetic Field and a Conducting Envelope. (The work was carried out in 1953 and was reworked in preparation for publication)-new graphs were given. The basic results were presented in a compressed form previously: Atomic Energy 5, 38, 1956. Analagous questions were discussed by M. D. Kruskal, M. Schwarzschild, Proc. Roy. Soc., A223, 348 (1954); R. J. Tayler, Proc. Phys. Soc., B70, 31, 1049 (1957); R. J. Tayler, Proc. Phys. Soc., B70, 1049 (1957); M. Rosenbluth, Proc. 3rd Jnt. Conf. on Ionization Phenomena in Gases, Venice (1957).) pp. 130-143.

"Investigation of the stability of a plasma pinch in the presence of a longitudinal magnetic field shows that there are two possible methods of stabilization of the column with the help of a longitudinal magnetic field:

(1) stability by means of internal frozen-in longitudinal field greater than the external field in the presence of an envelope. In that case, there is a region of stability with respect to arbitrary excitation. (2) Stability in the presence of a strong external longitudinal field. In that case, a calculation made in the linear approximation, shows that not all forms of excitation can be stabilized. It is possible, however, to stabilize at the same time the more dangerous excitation of the form of attractions and perturbations at which the axis of the pinch is displaced from its equilibrium position.

"I wish to express deep appreciation to Academician M. A. Leontovich and to S. I. Braginski for help and valuable advice. Likewise, I thank G. I. Beryuk for numerical calculations."

T. F. Volkov: The Stability of a Plasma Cylinder in an External Magnetic Field. (Work - 1953); pp.144-149.

"This article investigates the question of the stability with respect to perturbations of a type of attractions of the plasma cylinder with a current in an external field directed along the axis. It is assumed that the current is distributed uniformly in cross section. It is shown that for a sufficiently large magnetic field the perturbations of the type examined are stable." . . .

"The author thanks Academician M. A. Leontovich for t discussion of this article and for advice."

N. A. Borzunov, D. V. Orlinski: Distribution of the Intensity of the Neutron Radiation along the Axis of a Straight Tube for a Strong Pulse Discharge in Deuterium. (Work - 1954); pp. 150-164.

"Conclusions:

"(1) The intensity of the neutron radiation of a strong pulse discharge in deuterium increases linearly with increase of the initial potential (from 30 to 50 kv). In addition to this, the neutron radiation of the discharge exceeds the cosmic background in the range of $N = 1.5 \times 10^{17}$ to 3.5×10^{18} atoms per 1 cm of length.

"(2) In determining the distribution curve, one does not obtain a reproducibility of results. This is evidence of the statistical character of the phenomena taking part in the discharge. Results of investigation of the experiments on a more broad tube (with a distance of the counters to the axis of 20.5 cm) give a basis for the conclusion that the neutron radiation is not distributed uniformly along the leg length but is concentrated on definite rather small regions which may be several in number. (In other words, the neutron radiation in the discharge has a local character ~~in-i~~ and is concentrated in a region of the order of diameter of a discharge tube.

"The authors express their deep thanks to S. M. Osovets, L. I. Artsimovich, A. M. Andrianov for interest shown by them to this work and for valuable advice and its discussion."

S. M. Csovets: Mechanism of the Observed Neutron Emission. (Work - 1954); pp. 165-169.

"In the process of investigating the phenomena which arise when powerful pulse discharges are made in deuterium, it was found that under definite conditions in such a discharge there is a noticeable neutron emission which is accompanied usually with the emission of hard X-ray quanta. (L. A. Artsimovich and A. M. Andrianov, etc., Atomic Energy, 3, 1956; and S. Yu. Luk'yanov, I. N. Podgorni, Atomic Energy, 3, 1956.)

"In the present note we are presenting speculations on the basis of which one can make the conclusion that under these conditions the mechanism of neutron emission cannot be explained in principle by processes associated with the course of thermonuclear reactions. It is shown that in such a system of nuclear reactions $D + D = He^3 + n$ the observed intensities may take place only because of interactions of deuterons with energies many times greater than the temperature of the plasma. We present several estimates for a typical installation on which one can observe clearly the neutron radiation."

V. S. Komel'kov, T. I. Morozova, Yu. V. Skvortsov: Investigation of a Powerful Electric Discharge in Deuterium. (Work - 1954); pp.170-184.

"Oscillographs I, V are given for a discharge in deuterium for $C = 24$ to 36 mkf, $I_{max.} = 650$ ka diameter of the chamber 630 mm for the pressure range of 0.0025 to 0.1 mm mercury and for initial potentials $V_0 = 42$ to 100 kv. We observed several 'peculiarities' in the current. The integral yield of neutrons was registered in its dependence on C, V_0 ϑ_0. The moments of the appearance and the length of the neutron pulses was determined. An investigation was made of the X-radiation accompanying the neutron emission."

This article contains experimental data, a diagram ~~where they~~ with a scale of the apparatus, the electronic characteristics of the circuit and, in all, 20 figures.

"In conclusion, the authors express their thanks for advice and participation in the discussion of the results to A. M. Andrianov and S. N. Osovets, and likewise for technical help to G. N. Aretov, A. L. Bezbatchenko, and to the Laboratory technician P. T. Shevtsov."

A. N. ~~Ad~~ Andrianov , O. A. Bazilevskaya, Yu. G. Prokhrov: Investigations of a Pulse Discharge in Gases for Current Strength of 500 KA. (Work - 1954//, 1956); pp. 185-211.

"This is an experimental article, with 12 diagrams.

"In the present article, results are presented on the measurement of the distribution of the magnetic and electric fields within a powerful gas discharge. These measurements are part of a large cycle of work for investigating pulse discharges in gases for high current strength (cf. Atomic Energy, 3, 1956). The basic goal was the investigation of discharges in deuterium, but in addition to this, we have also investigated discharges in other gases (hydrogen, helium, argon, xenon). "

The sub-headings of this article are: (1) Description of the Apparatus and the Installation; (2) General Characteristics of a Powerful Gas Discharge; (3) ~~Dete~~ Distribution of the Magnetic Field and the Current Density in the Cross-Section of the Discharge; (4) Longitudinal Electric Fields in the Gas Discharge."

"We consider it our pleasant duty to express our deep thanks to Academician L. A. Artismovich and Academician M. A. Leontovich for valuable advice and unfailing interest in this work."

V. D. Kirillov: Measurement of the Conductivity of the Plasma for the Passage of Current for a Long Time. (Work - 1954); pp.212-225.

"The work describes the methods and experimental results of investigating a powerful (for currents up to 95 ka) low frequency (f is equal to 270 cps) discharge in deuterium."

Oscillographs are given of the voltage for discharges with a longitudinal magnetic field and without it, for curves of the change of the inter-electrode resistance as a function of time, high-speed photographs for the potential at the condensors equal to 6 kv and the curves for the distribution of the potential along the axis of the discharge tube. . .

"The experimental results with low frequency gas discharge showed that: (1) the discharge begins in the center of the camera; (2) the plasma pinch retaining its stability expands toward the walls. During the time of expansion the total resistance of the gas discharge drops. (3) At the end of the 'plateau', which corresponds to the expansion, the conductivity stops increasing, reaching the value of 5 to 15 x 10^{13} CGSE independent of the conditions. (4) With increase of ~~dI~~ dI/dt, the length of the plateau decreases. (5) The potential of the electric field is strongly inhomogeneous along the axis of the chamber. The author expresses his thanks to N. A. ~~Yavil~~ Yavlinski for his interest and help in this work."

This article contains 11 figures, among them 2 diagrams of the experimental set-up.

V. V. Babikov: The Theory of Bremmstrahlen for Non-Relativistic Radiation. (Work - 1954); pp.226-236.

"Corrections were obtained to the important members of the Born and quasi-classical approximation for the spectral distribution of the intensity of the Bremmstrahlen of electrons in a Gel Coulomb field. . . .

"In conclusion, we wish to thank V. I. Kogan for setting up the question and valuable advice. Note added in proof. Questions analagous to those investigated above were examined in the following recent work: K. Kummerer, Z. Phys., 147, 373, 1957; Th. Guggenberger, Z. Phys. 149, 523, 1957."

S. M. Osovets: A Plasma Discharge in an Electro-Magnetic Field. (Work - 1953); pp.238-241.

"In the present article we are presenting the basis of the theory of an electrodeless gas discharge of a definite configuration. In the discharge of this type conditions may ~~exist~~ EXIST be realized up to a certain degree analagous to those which take place in the acceleration of electrons in a vacuum betatron. Just as in the betatron there is a possibility of increasing the electrons, so in the gas discharge considered here one may heat the plasma. . . .

"In conclusion, we wish to bring our deep thanks to A. B. Migdal for the great help in carrying out the present work."

S. M. Osovets, Yu. F. Petrov, N. I. Schedrin: Investigation of a Gas Discharge in a Uni-Connected Region. (Work - 1955); pp.242-263.

"In this work results are given of the investigation of a gas discharge in a uni-connected region arising under the action of a variable magnetic field. It is shown that in this case a plasma pinch is formed which is compressed to the center of the discharge vessel. The theoretical investigations show that the choice of a special form of a magnetic field may give a region in which such a plasma pinch is in a state of equilibrium. The investigations were carried out on a system with a magnetic field satisfying these conditions. In this system, hard X-radiation was observed (several hundredths of kilo electron volts) indicating the fundamental possibility of obtaining in installations of this type a betatron acceleration of electrons without preliminary injection."

This article contains ~~16~~ 27 figures and 6 tables.

Yu. F. Nasedkin: Investigation of a Ring Gas Discharge in a Transverse Magnetic Field. (Work - 1955); pp. 264-282.

"With the purpose of decreasing the influence of the active resistance of a gas pinch on the course of the discharge, an installation presented in this work was constructed. It insures the necessary form of the magnetic field and has a small inductance equal to 0.15 micro-henries and a large coefficient of coupling (K = 0.35). The distribution of the secondary current in the volume of the chamber was studied.

"The results of the experiments give a basis for considering that in the course of the first half period, the secondary current is torn away from the walls and situated near the calculated stable orbit. In the region of the maximum primary current, the secondary current is torn away from the orbit and moves toward the center as a unit. In the second and subsequent semi-periods, the discharge fills the whole volume.

"In conclusion, we wish to express thanks to S. N. Osovets for discussion of the results."

<u>C. T. Belyev, G. I. Budker</u>: Relativistic Plasma in Variable Fields. (Work - 1953); pp. 283-329.

"In this work an investigation is made of the behavior of a relativistic gas of charged particles present in a strong constant-in-time and, generally speaking, non-homogeneous magnetic and electric field with √ an exciting variable electro-magnetic field, the frequency of which is much greater than the frequency of collisions so that one can neglect the latter."

<u>G. I. Budker, S. T. Belyev</u>: Kinetic Equation for an Electron Gas for Rare Collisions. (Work - 1954) pp. 330-354.

"A method of simplifying kinetic equations for rare collisions is proposed. A corresponding equation is found for a relativistic gas which ~~uses-for-its-stationary-state~~ can be used for the investigation of a stationary state of a stabilized electron beam."

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PLASMA PHYSICS
AND THE
PROBLEM OF THE CONTROLLED THERMONUCLEAR REACTIONS

VOLUME III

G. I. Budker: Thermonuclear Reactions in a System with Magnetic Mirrors. The question of direct transformation of nuclear energy into electrical energy (work done in 1954), page 3 to 31.

"The physical principles and preliminary calculations are presented in this investigation concerning the methods proposed by the author for realizing the thermonuclear reaction in a straight cylinder closed at the ends with magnetic mirrors. A method is investigated for igniting the discharge in a high vacuum and for heating the plasma with the help of a magnetic piston. In addition to this, an examination is made of the question of direct transformation of nuclear energy into electrical energy."

The references at the end of the article are exclusively to Soviet work either in these volumes or to Landau, 1937.

G. I. Budker: Several problems associated with spatial/~~ability~~ stability of a ring current in plasma (work completed in 1951), page 32 to 40.

"This investigation considers several problems associated with the stability of the ring current in plasma. Only stabilities associated with slow changes are investigated. The times of changes are such that equilibrium is able to be established for temperature and density. Rapid changes and others with so-called inertial times are not investigated. The work is a text of a report which was read by the author at a seminar in June, 1951."

S. T. Belyeev, G. I. Budker: Multi-Quanta Recombination in an Ionized Gas. (Work carried out in 1955), page 41 to 49.

"With the help of a classical kinetic equation we have investigated the process of electron transition to the ground level of the atom, using multiple collisions and emission of small quanta. We have used the method of approximate kinetic equations for rare collisions."

S. T. Belyeev: Kinetic Equations for Dilute Gases in Strong Fields. (Work carried out in 1955), page 50 to 65.

"A method is developed for obtaining approximate kinetic equations for dilute ionized gases in strong external fields. The small parameter of approximation is the ratio of the period of proper vibrations of the particles in an external field to the time of the mean free path. The approximate equation has the form of the Fokker-Planck equation with a smaller number of variables."

There are two references to R. P. Feynman, Phys. Rev., 76, 749 (1949) and 84, 108 (1951).

S. T. Belyeev: The Kinetics of an Ionized Gas in a Strong Magnetic Field. (Work carried out in 1955), page 66 to 85.

"An ionized gas in a strong magnetic field is considered as an ensemble of Larmor rings. A kinetic equation is obtained for the distribution functian of the Larmor rings. Its solution is examined in the hydro-dynamic approximation. The co-efficient of the electron-ion diffusion is calculated for a uniform magnetic field. In an homogeneous field the currents are found, if one does not consider collisions."

The references at the end of the article are ~~two~~ to Russian authors in these volumes and to E. S. Fradkin, Journal of Experimental and Theoretical Physics, 32, 1176 (1957), and to K. M. Watson, Phys. Rev., 102, 12 (1956), and L. Spitzer, Physics of fully ionized gases, N. Y. Interscience Publishers, 1956.

<u>V. V. Babikov, and V. I. Kogan</u>: Radiant Heat Losses of a Dense High Temperature Plasma. (Work carried out in 1955), page 86 to 98.

Because of its application to the problem of heating dense or condensed media, a calculation is made of the heat loss of a layer of plasma in consequence of the Bremmstrahlen for arbitrary degree of its transparency. The transition from "transparent" emission to black emission is investigated.

"In the present article the question of radiant opaqueness and radiant heat losses of a dense high temperature plasma is investigated for those values of its density, temperature, and size when one or the other of two limiting cases is not applicable in general. One, the free yield of the Bremmstrahlen from the whole volume of the plasma and, two, the black radiation from the surface of the plasma is strongly forbidden for the radiation in it. Investigation of this question has a significant meaning for the problem of heating dense or condensed media to temperatures at which thermonuclear reactions can be excited. The problem is this that ~~from one~~ on one hand the heat loss by the mechanism of Bremmstrahlen is the main component in the complete heat loss of the plasma for a wide range of changes of the parameters, and on the other hand there is a transition from the case of a transparent medium to a case of "black" medium in a considerable portion of the designated range.

"Inasmuch as under the conditions examined (density of the plasma $10^{19} \div 10^{23}$ cm^{-3} interval and temperature 10 ev $\div$ 1 kev interval) the plasma is practically completely ionized the basic mechanism of the absorption of radiation, due to the opacity of the plasma, is the Bremmstrahlen (photo effect on free electrons)."

<u>V. I. Kogan</u>: Recombination Radiation of a Hydrogen Plasma. (Work carried out in 1956), page 99 to 103.

"A calculation is made of the complete intensity of recombination radiation of a dilute hydrogen plasma as a function of the electron temperature (with consideration of recombination at excited levels). A comparison is made of this quantity with the intensity of the Bremmstrahlen.

"The basic mechanism of radiant heat loss of high temperature ($T > 100$ ev) hydrogen plasma is, as is well known, the Bremmstrahlen. On the other hand, for sufficiently low electron temperatures (of the order of several electron volts) the dominant contribution in the total radiation is given by the processes of recombination of electrons with ions. Therefore, for comparatively low temperatures (less than tens of electron volts) it is of interest to calculate the intensity of the recombination radiation and to compare it with the intensity of the Bremmstrahlen."

A figure is given in which it is shown that the intensity of the recombination radiation decreases linearly as a function of the electron temperature while the radiation due to Bremmstrahlen increases with electron temperature giving for the total losses a minimum at a temperature of about 30 electron volts.

B. A. Trubnikov: (Work Carried out in 1956, page 104 to 113.) Electro-Magnetic Waves in a Relativistic Plasma in the Presence of a Magnetic Field.

"In this investigation we have obtained the relativistic tensor for the dielectric susceptibility of a plasma which is situated in a homogeneous magnetic field. The heat motion of the electrons is described by a Maxwell (relativistic) distribution. Collisions are considered rare. With the help of the dispersion equation we have investigated the propagation of waves of the form $\exp\left[i\ (kr - \omega)\right.$. For frequencies $\omega \gg \left(\frac{eH}{mc}\right)$ we have calculated the radiation ability of the medium and the absorption co-efficients of "ordinary" and "non-ordinary" waves.

"The dielectric properties of a relativistic plasma which is present in a magnetic field is first discussed in the work of V. M. Galitski and A. B. Migdal (Vol. I, page 161). Using a quantum mechanical approach, the authors found for the tensor an expression having cumbersome series. In the present investigation this same problem is examined classically and we were able to obtain for the tensor a rather simple formula." Academician M. A. Leontovich has assisted in this work."

V. S. Kudryevtsev: The Distribution Function of Electrons in a Plasma Situated in a Magnetic Field. (Work carried out in 1956, pages 114 to 120.)

"A distribution function for electrons is calculated for a two-temperature plasma for the case when the electrons by collisions obtain energy from the ions at high temperature and emit itby motion in a magnetic field. The stationary process is examined and the plasma is considered completely transparent.

B. S. Trubnikov and A. E. Bazhanova: Magnetic Emission of a Layer of Plasma. (Work carried out in 1957), pages 121 to 147.

"In this work calculation is made of the magnetic deccelerating radiation of a plane layer of plasma situated in an external magnetic field parallel to the boundaries of the layer. The weakly-relativistic energies of the electrons are investigated. Calculations are carried out for two forms of energy distribution of electrons - Maxwell and a cut-off Maxwell distribution. It is shown that the degree of forbiddeness of the thermonuclear reactor DD is reached only for large sizes of the layerwhich lie within the limits of technical realization."

This is a rather long article with nine figures and nine tables and three ~~two~~ full appendices. The tables give the values of the dimensions of the plasma at which losses by radiation are not deleterious .

"The size of the layer a_{min} obtained above (from 3.9 meters to 2.1 kilometers) necessary for the self-sustainment of the DD reaction in installations where within the ~~ma-~~ plasma there is a considerable magnetic field characterizes the difficulties of realizing such systems. For the reaction of a DT mixture there is a region of temperatures from 7 to 45 kev where the production of nuclear energy on charged particles is greater than the losses by radiation emission. For decreasing the losses by magnetic radiation special measures must be taken and in particular as was shown by G. I. Budker, it is possible to use effective mirrors which return the ~~radiat~~ radiant energy back into the plasma. We will note also that magnetic radiation losses are absent in systems where the containment of the plasma is realized by high frequency ~~extenera~~ external fields which do not penetrate within the plasma.

"In conclusion, the authors express their deep appreciation to Academician M. A. Leontovich for valuable advice and direction given during the course of this investigation and to J. I. Beryuk for help in organizing the numerical calculations."

<u>T. F. Volkov:</u> The Problem of the Decomposition of an Arbitrary Shock in a Continuous Medium. (Work carried out in 1956), pages 148-152.

"In this investigation we have investigated the particular case of the breakdown of an arbitrary shock in a continuous medium with the purpose of obtaining an evaluation of temperatures which may be obtained by collision of dense beams of particles one with another or with a solid target. Short considerations are also given to the possibility of the influence of a magnetic field.

"The problem of the decomposition of an arbitrary shock in a continuous medium is of some interest in connection with the discussion of the possibility of obtaining high temperatures by means of collisions of considerably dense cluster of particles one with another or a cluster of particles of high energy with a solid target. The problem is solved by methods of gas dynamics. This means that the colliding masses have either considerably large densities or considerably large dimensions. At the moment of collision one obtains an arbitrary shock which, speaking generally, the conditions Hugonio relation is not satified. Such a shock cannot be stable and must decompose. It is interesting to evaluate the maximum possible temperatures which can be obtained, the velocities of the divergent shock fronts and also calculate the influence of the magnetic field. We shall assume that the calculating masses have an infinite width, i.e., that the particles do not fly out sideways and that there are no radiation losses.

"Such a picture obviously ~~is~~ represents highly idealized conditions which cannot be met in installations of the laboratory type. However, it can be realized on collisions of gas masses of cosmic dimensions."

L. I. Rudakov, and R. Z. Sagdeev: High Frequency Heating of Plasma. (Work carried out in 1956), pages 153-164.

"In the present report we have investigated the method of heating the ions of the plasma based on using cyclotron resonance. Consideration of the characteristic fields of the plasma produced by the motion of ions and electrons can significantly change the character of the motion of the particles, violating the conditions of heating. In order to clear up the conditions under which acceleration of ions is possible we have investigated in Part I the problem of the motion of the particles in an external field without considering the influence of the characteristic self-consistent field of the plasma. The analysis of the influence of the self-consistent field of the plasma is carried out in Part II within the framework of the hydro-dynamic approximation. . .

"In conclusion, we wish to thank M. A. Leontovich, G. I. Budker, and M. S. Yoffe for valuable direction and discussion of the work in the process of its execution."

S. M. Osovets: Theory of Rapid Processes. (Work carried out in 1957); pages 165-181.

"In this article calculations are made which characterize the process of a rapid compression of a plasma column with consideration of the changing induction of the contour. Basic relationships are obtained for the temperature of the compressed column and the time of compression. Conditions are examined for the disengagement of the plasma column from the walls of the vessel and a calculation is made of the mean temperature of the gas up to the moment of disengagement."

The article contains 10 figures, among them 2 photographic plates of various plasma conditions.

Yu. F. Nasedkin and S. M. Osovets: Investigation of a Powerful Ring Gas Discharge in the Presence of an Equilibrium Orbit. (Work carried out in 1956); pages 182-195.

This is an experimental paper which contains 10 diagrams with descriptions and dimensions of the apparatus and oscillographs of the magnetic fields and current under various conditions.

"This investigation deals with the study of a powerful ring gas discharge under the influence of a variable magnetic field of special construction which insures the presence of an equilibrium stability in the current orbit. The distribution of the current in the volume of the vacuum chamber is studied. The maximum energy of the motion of the turbulence to the center of the chamber after its disengagement from the orbit is evaluated. It is about 1500 electron volts. An evaluation is made of the residual magnetic flow and active resistance of the gas turbulence."

S. M. Osovets and N. I. Schedrin: Plasma Turbulence in the Presence of Active Resistance. (Work carried out in 1957); pages 196-213.

"The first part of the article gives a theoretical investigation of the equilibrium conditions in the process of compression of a plasma turbulence for finite conductivity. It is shown that for the compression of the turbulence it is necessary to compensate the residual magnetic current by some field constant in time. In the second part, experimental results are given of compensating fields which confirm the conclusions of the first part. Conditions are obtained in which the residual current is completely compensated and the turbulence is compressed into a ball."

There are 14 figures in this article, with a diagram of the experimental set-up, and numerous oscillographs.

"Experiments have shown that with the rapid motion of the gas turbulence to the center about 1/4 of the internal magnetic current is frozen inside. This residual field hinders the compression of the orbits to smaller dimensions. In addition, part of the magnetic energy is spent on the building up of the field. If one uses additional central field, then for a given value of this field one observes a compensation of the residual current. In this case, one should expect that the magnetic energy will basically go over into kinetic energy of directed motion of the particles to the center with the consequent formation of a dense "ball"."

<u>Yu. F. Nasedkin and E. I. Pavlov</u>: The Influence of the Form of the Magnetic Field on the Ring Gas Discharge. (Work carried out in 1957); pages 214-230.

"A study is made of the behavior of a current gas pinch in a betatron field and the subsequent distribution of the current density along the cross-section of the chamber. It was found that the form of the field has an influence on the behavior of a current pinch. For small gas pressures in the chamber X-ray emission was detected. The experiments were carried out with deuterium and argon."

This is an experimental paper in which 15 figures are presented, includig four on the form and dimensions of the apparatus. The others represent oscillographs. There are 5 tables and 2 pages of discussion of the experimental results.

N. V. Filippov: Investigation of the Pressures in a Powerful Pulse Gas Discharge with the Help of a Piezo Electric Measuring Device. (Work carried out in 1956); pages 231-249.

"In this work a description is given of the construction of a Piezo Electric Measuring Device for measuring pressures in a pulse discharge and the method of working with this device in a cylindrical discharge chamber with currents from 300 to 500 ka. Results of investigations of the pressure near the center of the chamber are given for a discharge in deuterium of a battery of condensers with 62 mkf. capacity. A new method is described for callibrating this device directly in the investigated gas discharge with the help of a diaphragm inertial device."

There are 13 figures in the article and 3 detailed diagrams of the apparatus with dimensions given.

G. M. Antropov, V. A. Belyeev, and M. K. Romanovski: The Behavior of Rapid Electrons in an Electron Model of a Trap with Magnetic Mirrors. (Work carried out in 1957); pages 250-258.

"One of the methods of creating a hot plasma can be the accumulation of rapid ions in a volume with a magnetic field of a special form in which the particles are kept for a long time from hitting the walls. In such magnetic traps regions with large values of H play the role of mirrors from which the charged particles are reflected corresponding to the invariance of the quantity V^2/H in a magnetic field which changes but little during the extent of the Larmor radius of the particle. The simplest form of the magnetic trap is the field of a straight solenoid, which is increased at the ends. This form was investigated using an electron model even though this is not the only one nor possibly the best configuration of the magnetic field of the trap. . . ."

"Conclusions:

(1) The injected electrons moving in a magnetic field of the trap with magnetic mirrors make up to a thousand ~~vibr~~ vibrations between the mirrors.

(2) The lifetime of rapid electrons in the system is determined not by the conservation of the adiabatic invariant but by the interaction of the electrons with the residual gas and by their destruction on the source."

<u>O. B. Firsov</u>: The Repulsion of Charged Particles from Regions of Strong Magnetic Fields. (Work carried out in 1956) ~~throu~~ pages 259-267.

"This work attempts to determine the validity of the adiabatic invariant for the conditions found in magnetic traps with axially symetric field.

<u>L. I. Rudakov and R. Z. Sagdeev</u>: A Quasi-Hydrodynamic Description of a Dilute Plasma in a Magnetic Field. (Work carried out in 1957), pages 268-277.

"The kinetic equations which describe the motion of the ions of a plasma in a magnetic field in the absence of collisions and averaged with respect to the Larmor rotation, is generalized for the non-static case. The system of equations for the lower moments of the distribution function of the electrons and the ions is analogous to the equations of ~~a~~ 2-liquid hydrodynamics. While formally the mean free path is infinite, its role is played by the Larmor radius of the ion (electron). With the help of the equations obtained, we have investigated the wave equations corresponding to magnetic-hydrodynamic and acoustical vibrations. For a sufficiently large anisotropy of the tensor of pressure one obtains instabilities which lead to the destruction of the homogeneity of the plasma. The study of the motion of the completely ionized plasma in strong electromagnetic fields considering their own fields with the help of kinetic equations is rather difficult. The usual hydrodynamic consideration is valid only for large densities and low temperatures when the mean free path between collisions is many times lower the characteristic size. Recently G. Chew, M. Goldberger, F. Low., Proc. Roy, Soc., 236, 112 (1956), investigated the case of a dilute plasma which is in a magnetic field neglecting collisions. This consideration showed that the expansion of the kinetic equation in powers of M/e leads to a closed system of equations for the lower moments of the distribution function formally analagous to the system of equations of magnetic hydrodynamics. However, this is valid only for the motion of plasma across the magnetic field. This similarity of results obtained in two apparently completely opposite cases is explained by the fact that the magnetic field 'turning over' ions makes symetrical the distribution of their velocities in a plane perpendicular to the magnetic field. In this sense the action of the magnetic field is analagous to the action of the collisions. In this note we are deducing the equations of hydrodynamics of two liquids (ions and electrons) starting from kinetic equations describing the averaging of the motion of the ions with respect to the Larmor rotation."

"In conclusion we wish to express our appreciation to Academician M. A. Leontovich, to Prof. D. A. Frank-Kamenetzki, and to S. E. Braginski for valuable discussions and constant attention to this work."

<u>A. A. Vedehov and R. Z. Sagdeev</u>: Some Properties of the Plasma with Anisotropic Distribution of the Velocities of Ions in the Magnetic Field. (Work carried out in 1957); pages 278-284.

"In the usual gas with non-Maxwellian distribution of velocities equilibrium is established in time of order of magnitude of that between collisions. In the plasma the long-range forces may cause collective motion developing in time smaller than (example of such collective motion is the formation of Langmuir vibrations in the plasma for non-Maxwellian distribution of electron velocities. "

D. Bohm, E. Gross, Phys. Rev., 75, 1864 (1949).

"The influence of the internal magnetic field on these effects was studied by E. Gross, Phys. Rev. 82, 232, (1951) on the basis of a kinetic equation.

"Investigating the electronic branch of the vibrational plasma, Gross naturally neglected the proper magnetic field of the waves as an effect of the order v/c. The situation changes substantially if we are talking about the ionic (magneto-hydrodynamic) wave branch. Actually the electrical field in the low frequency vibrations strongly shield the motion of the electrons and magnetic effects may play an important role. In the article by Rudakov and Sagdeev, present Vol. 268, from equations for the moments of the distribution function in the drift approximation we criteria were obtained for the formation of specific instabilities for strong anisotropy of temperatures, longitudinal and t5a transverse. These considerations correspond to a hydrodynamic derivation of the dispersion equation. In the present work this question is investigated with the help of the kinetic equation and criteria are feuhd found for instability neglecting collisions. Consideration of the proper magnetic field of the waves for a sufficiently anisotropic distribution function leads to a "transfer" of energy of logitudinal motion into the energy of the transverse motion (or vice-versa) by means of collective motion excitation which is associated with the ionic branch of plasma vibrations. . . .

"In conclusion, the authors wish to express sincere thanks to Academician N. A. Leontovich and to Prof. D. A. Frank-Kamentski for valuable advice and discussion."

<u>B. B. Kadomtsev</u>: Magnetic Traps with "Gofrirovanoe" Field. (Work carried out in 1956); pages 285-299.

"We are describing here two simplest traps with "Gofrirovanoe" magnetic field, the principle of the action of which is based on the increased drift of particles by the axis of the system by placing additional periodic field. The first of these works analagously to a simple trap with magnetic mirrors, i.e., the exit of particles from it is determined by the Coulomb collisions. In the second case the basic exit of particles arises from a toroidal drift and in this sense it is closer to the torrus. It is probable that there are more perfect traps of this type and for this reason it is of interest to study in more detail the motion of particles in magnetic traps which will, we hope, permit us to select the best configuration. Great interest, however, is given to the study of the behavior in such traps, not only of individual particles but plasma with consideration of proper electric and magnetic fields and other complicating factors. In particular, it is necessary to carry out investigations of the coresjonding systems for their stability.

"In conclusion, we express deep thanks to Academician L. A. Artsimovich and Academician M. A. Leontovich for detailed discussion of the work and a series of valuable directions."

S. I. Braginski and B. B. Kadomtsev: Stabilization of Plasma with the Help of Shielding Conductors. (Work carried out in 1957); pages 300-326.

"In this work a method is proposed for stabilizing the boundaries of plasma, the pressure of which is equilibrated by the magnetic field. The stability of the boundary is obtained with the help of "shielding" conductors. They form a lattice which is placed on the boundary of the plasma and takes on itself part of the pressure of the magnetic field. This excess pressure does not permit the plasma to go behen beyond the limits of the lattice. Stability of such a system is shown with respect to small vibrations. An investigation has been made about the form of the boundary of the plasma near the rods of the lattice."

The article contains 20 figures of various configurations and the following section headings: (1) Action of Shielding Conductors; (2) Plane Lattice; (3) Conditions of Stability. The references at the end of the article are two: M. Kruskal, M. Schwarzchild, Proc. Roy. Soc., A 223, 348 (1954); and W. B. Thompson, Proc. Phys. Soc., 70 B, No. 1 [illegible] (1957).

"We express our thanks to Academician N. A. Leontovich for discussion of this work."

O. B. Firsov: Plasma in "Magnetic Net." (Work Carried out in 1957); pages 327-335.

"An investigation has been made of the Escape of an electron-ion plasma from a volume surrounded by a constant magnetic field along the lines of force of the magnetic field. The configuration of the magnetic field is such that inside the plasma the field is absent. The possibilities of applying such a system for construction of a thermonuclear reactor are considered."

T. F. Volkov: Stationary Distribution of the Density of the Plasma in an Electro-Magnetic Field. (Work Carried out in 1957 and supplemented for preparation for publication in 1958); pages 336-345.

"In the framework of hydrodynamics the problem has been solved for the stationary self-consistent distribution of density of plasma in a standing electro-magnetic wave. It is shown that in the hydrodynamic statement of the problem exact solutions are absent for which the density of the plasma in any region of space is equal to zero. An investigation has been made of the influence of the magnetic field and of the walls limiting the plasma." . . . .

"The author thanks Academician N. A. Leontovich for the discussion of the results and valuable advice."

R. Z. Sagdeev: Containment of the Plasma by the Pressure of a Standing Electro-Magnetic Wave. (Work carried out in 1957); pages 346-361.

"In recent times it has been of general interest to consider the problem of containing a high temperature plasma in a high-frequency electro-magnetic field. At the basis of the possibility of such a containment is the fact that an alternating electro-magnetic field does not penetrate into a conductor and in this way causes a discontinuity of pressure at the boundary of the conductor. This principle has been used in the well-known experiments for counteracting the forces of gravity by the pondero motive forces ofFoucalt currents arising in the skin layer of solid conductors. In the present investigation some of the problems shall be investigated concerning the equilibrium and the stability of the heated plasma contained by the pressure of the alternating electro-magnetic field.

"In a series of cases the plasma can be described with a sufficient degree of accuracy by the equations of hydrodynamics. The criterion of applicability of such an approach is the small magnitude of the mean free path of the ion (electron) compared with the characteristic size L. The Coulomb collision cross section decreases with increase of the relative energy of the colliding particles as the inverse square of the energy. This affects in a crucial way on the criteria of applicability of the equations of hydrodynamics: in the practically interesting cases the range of temperature corresponding to a strongly ionized plasma lies outside of the regions of the hydrodynamic approximation. In the presence of the constant magnetic field this criterion, however, can be replaced by another one at least for the description of the motion of the plasma across the magnetic field and particularly by the condition of the small magnitude of the Larmor radius of the ion (electron) with respect to L.

"In the general case for the description of the plasma it is necessary to use a system of kinetic equations for each type of ion. This approach, however, is extraordinarily complex and we doubt whether it permits obtaining any concrete results. A good approximation for the description of the high temperature plasma can be the consideration of the kinetic equations without the collision integral with a later consideration of the collisions as a small correction. In the present article we investigate the case of a plasma which has such high temperature of ions and electrons that collisions can be neglected as a basis of the consideration of the equilibrium state we use the method of kinetic equations without the collision term but with consideration of the self-consistent electro-magnetic field.

"In conclusion, we have investigated in the framework of the equations of hydrodynamics the question of the stability of the boundary between the heated plasma and the standing electro-magnetic wave."

. . . "In conclusion, I wish to thank Academician M. A. Leontovich, S. M. Osovets, and Prof. D. A. Frank-Kamentski, for discussions.

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PLASMA PHYSICS
AND THE
PROBLEM OF THE CONTROLLED THERMONUCLEAR REACTIONS

VOLUME IV

S. M. Osovets: Containment of a Plasma by Traveling Magnetic Field. (Work Carried out in 1957); pages 3-15.

"Investigation is made of the question of containing a hot plasma by means of a field of a traveling wave. Expressions are obtained for magnetic fields and magnetic pressures produced on the surface of the plasma by a system of currents displaced in phase with respect to one another by some angle. Conditions are found under which the excitation of the surface of the plasma can be considered small. Starting from these conditions, relations are found which determine the basic parameters of the contour which produce the traveling field. Relations are presented characterizing the energetic balance of the thermonuclear reactor in which the plasma is contained by the traveling field. . . ."

B. B. Kadomtsev: Hydrodynamics of a Plasma of Low Pressure. (Work carried out in 1957); pages 16-23.

"In the work we have obtained approximate equations of motion of a plasma, the pressures of which are many times lower than the pressure of the magnetic field. The question of equilibrium and stability of such a plasma is discussed." . . . .

"For the discussion of the work we wish to thank Academician M. A. Leontovich."

The author obtains the M. Rosenbluth, C. Longmire, Ann. of Phys., 1, 120 (1957), condition.

S. I. Braginski, A. P. Kazantsev: Magneto Hydrodynamic Waves in a Dilute Plasma. (Work carried out in 1957); pages 24-31.

"An investigation is made of the magneto hydrodynamic wave with an arbitrary direction of propagation starting out from kinetic equations with a self-consistent field without consideration of collisions. Just as in a conducting liquid, in a dilute plasma one can consider in the general case three types of magneto hydrodynamic waves. It is shown that in the absence of collisions these waves undergo a characteristic decay."

The references at the end of the article include, among others, the work of I. B. Bernstein, Phys. Rev., 109, 10 (1958).

L. S. Solov'ev: The Motion of Charged Particles in a Magnetic Trap. (Work carried out in 1957); pages 32-41.

"In the approximation of the drift theory a calculation is made of the motion of a particle in the field of a trap with magnetic mirrors. The length of the trajectory of the particle, the tolerance for the curvature of the axis of the trap, and the influence of supplementary gaps of the field on the axis are determined. . . . For a given parabolic approximation of the field on the axis it is possible to integrate in a closed fie form the the equations of motion of the particle."

A. A. Vedenov, L. I. Rudakov: The Motion of a Charged Particle in the Rapidly Alternating Electro-Magnetic Fields. (Work carried out in 1958); pages 43-48.

"In a series of investigations the motion of particles has been investigated in magnetic and electric fields slowly varying in time and space. The

solution was obtained in the form of a series with increasing orders of
small parameters $\frac{\Omega}{\omega}, \frac{r_H}{L}$. (Ω is the frequency of change of the electro-
magnetic field, ~~the-sme~~ ω is the Larmor frequency, r is the Larmor radius,
L is the characteristic size of the change of the field in space.)

"In the present investigation it is shown in a concrete case how one
can remove the limitation $\frac{\Omega}{\omega} \ll 1$, using for finding the solution only
the small magnitude of r/L and δ/L, where δ is the displacement of the
particle in time 1/Ω . For presentation we shall use the designations
of Hellwig, Zs. f. Naturforsch, 10a, 508 (1955). . . .

"In conclusion, we wish to thank Academician M. A. Leontovich for
valuable discussion."

D. V. Orlinski: Stabilization of a Plasma with the Help of a System of
Rods. (Work carried out in 1958); pages 49-53.

"S. I. Braginski and B. B. Kadomtsev (Vol. III, page 300) proposed
for the stabilization of the plasma with a current to use transverse rods.
In the present note we are presenting results of experiments to study the
influence of transverse rods on the development of a pulse discharge in a
cylindrical chamber. These experiments have the purpose of obtaining
preliminary experimental data on the work of such a system." . . . .

"The author wishes to express his appreciation to Braginski, Kadomtsev,
Leontovich and Osovets for the discussion of the results of the present
work."

The article contains a diagram with dimensions of the experimental
set-up, 5 photographs of discharges in the cyclindrical chamber with and
without rods, and 2 figures of the variation of the current in time for
di[illegible] pressures of deuterium and different numbers of rods.

L. I. Rudakov, R. Z. Sagdeev: Investigation of the Stability of a Cylindrical Plasma Column by Methods of Kinetic Equations. (Work carried out in 1958); pages 54-69.

"An investigation was made of the stability of a ~~cycl~~ cylindrical plasma current column placed in a longitudinal magnetic field. The method of investigation was to use the kinetic expression in a "drift" approximation derived in the previous article, (Vol. III, page 268), with neglect of collisions. In the case of isotropy of the non-excited pressure, the criterion turns out to coincide with that obtained in the magneto hydrodynamic approximation. In the case of the inequality of the longitudinal and transverse components of pressure, there is a possibility of a new instability even in the absence of a current on the axis of the column."

The references at the end of the article include, among others, G. Chew, M. Goldberger, F. Low, Proc. Roy. Soc. A236, 112 (1956); K. Watson, Phys. Rev. 102, 12 (1956).

V. D. Shafranov (Shaffranov): Stability of a Plasma Column with a Distributed Current. (Work carried out in 1958); pages 61-69.

"The first investigations of the stability of the plasma column in the presence of a longitudinal magnetic field (Vol. I, page 207; and Vol. II, page 144) were based on ~~teh~~ the assumption that the whole current was concentrated in an infinitely small surface layer. . . . It was shown in this case that if the internal longitudinal field was greater than the outer field, then the column could be stable in the presence of a good conducting shell independently of the ratio of the length of the column to its radius.

In the reverse case the column could be of a limited length L. For the case when the internal field is equal to the external field, the condition of stability has the form $L < \sqrt{2\pi}\, a$. $h = cH_z / (J/\pi a^2)$. It is of some interest to clear up how these conditions are changed in the presence of volume currents. In the work of Volkov, Vol.II, p. 144, it was shown that the criterion of stability for an axially symetrical excitation in the case of a homogeneous axial current does not differ markedly from the stability criteria obtained for the case of surface currents.

"Usually it is considered more ~~rigorous~~ difficult to obtain criteria of stability with respect to the bending of the column and more complicated types of excitation. In the case of the homogeneous current, it was found possible to carry out rather simply an investigation of all these forms of excitation."

Among the references there are those two: P. H. Roberts, Ap. J., 124, 430 (1956); and R. J. Tayler, Proc. Phys. Soc., B 70, 1049 (1957).

<ins>N. N. Poliektov-Nikoladze</ins>: Calculation of Quasi-Stationary Electro-Magnetic Field in a System with Toroidal Symetry. (Work carried out in 1958); pages 70-80.

"The analytical calculations of non-stationary electro-magnetic fields in toroidal systems is extraordinarily difficult in view of the fact that Maxwell's equations in that case do not permit the separation of variables. In this work it is shown that for toroidally-symetrical thin conductors, the above difficulty disappears and the problem resolves itself to the solution, generally speaking, of a system of integral equations for functions with one independent variable which can be carried out rather simply by the usual numerical methods."

V. F. Demichev, Yu. G. Prokhorov: Investigation of the Neutron Emission Arising in a Gaseous Discharge with a Current of 160 KA. (Work carried out in 1957); pages 81-86.

"In this work an investigation is made of the neutron emission taking place in the gas discharge in a cylindrical tube with a current strength of 160 KA. It is shown that the neutron emission is due to the presence of deuterons on the discharge which are accelerated ~~f~~ to large energies."

This is an experimental paper with details of apparatus and data on the energy distribution of ~~energies-with-respec~~ neutrons.

"From the table it is seen that the ~~metu~~ neutron radiation is non-isotropic. Experimental data obtained are against the assumption of the localization of the source of the neutrons in a small region of a discharge and against the uniform distribution of the intensity of the source along the axis. These data are consistent only with the assumption that the intensity of the source of neutrons increases along the axis from the anode to the cathode. A qualitative evaluation shows that it must change according to x^{Ω}, where x is the distance along ~~from~~ the axis from the anode and Ω lies within the limits 1÷2. If we have in mind that the neutron emission arises in reactions with accelerated deuterons then such a result is completely consistent.

B. A. Trubnikov: A Possible Mechanism of the Neutron Effect at Massive Pulse Discharges in Deuterium. (Work done in 1958); pp. 87-97.

"The paper discusses a possible mechanism of the neutron effect in discharges in deuterium. The mechanism is based on the assumption that in the process of the development of unstable excitation of the plasma column the plasma may be completely pushed out by the pressure of the magnetic field from several regions of the column. In such perturbations strong electrical field may arise which may be the reason for the acceleration of deuterium ions causing a number of nuclear reactions."

"In conclusion, the author wishes to thank Academician M. A. Leontovich for his most valub valuable remarks and discussions of the work."

There is a reference to the paper of O. A. Anderson, W. R. Baker, S. A. Colgate , and others; Venice Conference, 1957. There is evidence from the Russian title that the proceedings had been translated into Russian. There is a discussion in the paper of the Colgate mechanism and the following remarks are made about it, in addition to others:

"Thus, in distinction to the Colgate work where the mechanism of acceleration in fields is assumed to take place before the moment of the formation of the perturbation we are considering acceleration in fields which arise after the formation of the perturbations. For the formation of sufficiently strong fields in the second mechanism we need simpler conditions. In particular, we do not have to assume that the radius of the conducting channel decreases to the size of the order of tenths of millimeter as was done in the Colgate work. In addition, it turns out that for the evaluation of the magnitude of the electric fields we do not have to know in general the microscopic picture of what takes place in the formation of the perturbation. Therefore, this whole description can be carried out phenomenologically.

T. F. Volkov: The Influence of a High Frequency Electro-Magnetic Field on the Vibrations of a Plasma. (Work carried out in 1958); pp. 98-108.

"In this article we are examining the hydrodynamic theory of the vibrations of a plasma in the field of a traveling electro-magnetic wave. It is shown that the frequencies of the acoustical and Langmuir vibrations in this case become functions of the amplitude of the high frequency field. The possible mechanisms for the formation of instabilities are discussed."

"The author thanks Academician M. A. Leontovich."

"The conditions of the problem demand that the frequency of the electro-magnetic field will be considerably larger than the frequencies of the Langmuir vibrations. This is realized pradically only in the case of a sufficiently diluted plasma. In conclusion, we note that the hydrodynamic solution of the problem presented here cannot be considered completely concrete because of the neglect of the thermal motion of the particles. A kinetic solution is necessary which the author hopes to carry out in the near future."

T. F. Volkov: The vibrations and stability of the surface plasma in the field of a traveling electro-magnetic wave.were (Work carried out in 1958); pp. 109-115.

"The paper considers the surface vibrations of a plasma in the field of a traveling high frequency electro-magnetic wave. It is shown that the plane surface of the plasma is in this case unstable, independently from the magnitude of the external electro-magnetic wave. The greatest increment is produced by excitations, the wave length of which is close to half the wave length of the electro-magnetic vibration. "

"The author thanks Academician M. A. Leontovich for the discussion of the paper and useful advice."

A. L. Bezbatchenko, I. N. Golovin, P. I. Kozlov, V. S. Strelkov, N. A. Yavlinski: The Electrodeless Discharge with High Current in a Toroidal Chamber with a Longitudinal Magnetic Field. (Work carried out in 1956-57); pp. 116-133.

"This is an experimental paper with 8 figures, a sh schematic diagram of the apparatus, oscillographs, and photographs of the radiation from the column. In addition, there are numerous graphs of the data.

"The installation with the toroidal chamber was designed and built for the study of the ignition and the propagation of an electrodeless discharge in a magnetic field and for the study of the heatt heating of the plasma to temperatures while not sufficient for the detection of neutrons from the thermonuclear reaction but corresponding to a high ionization of the plasma and to the frozen-in-state of the magnetic field."

"Conclusions: Investigation has been made of the electrodeless discharge in a toroidal chamber without a longitudinal magnetic field and with a longitudinal field of a potential up to ~~15~~ 15,000 oersteds with an electric field from 0.15 to 6.5 v/cm for the duration of the first half period of flow of current of the discharge from 350 to 2,000 microseconds and with the initial pressure of the deuterium from 7×10^{-4} to 0.2 mm.

"(1) In electrodeless discharge in a porcelain chamber the phenomena are complicated by the building up of a charge on the walls and drifts caused by crossed electric and magnetic fields. Placing a metallic layer on the walls facilitates the breakdown, increases the conductivity of the plasma and brings about the initial stage of the discharge into good relation with the classical theory of conductivity and wi5 with the Tewk Townsend coefficient α known in the literature. (2) The discharge without a longitudinal magnetic field arises in the center of the discharge tube; then the column of the discharge widens and fills the whole chamber. The velocity of the widening increases with decreased pressure and with the increased current rise velocity of the discharge. The average cross-section conductivity of the plasma does not increase over 3×10^{13} CGSE.

(3) The discharge in the strong longitudinal magnetic field ignites simultaneously in the whole cross section of the tube and does not break away from the walls. In the field of 15,000 oersteds the discharge goes through to two sharply different stages. In the field of 2500 oersteds these stages are washed out. In the first stage the plasma is quiet, the radiation is uniform along the cross section of the tube, the conductivity grows in good agreement with the classical theory of the plasma. In the second stage there is an intense redistribution of the current density and the radiation of the discharge according to the cross section . The conductivity decreases. For a field of 15,000 oersteds the first stage prevails to a current in the discharge satisfying the stability conditions

$$a > \sqrt{\frac{2 J_m R}{3 H}}$$

and where amis-the a is the radius of the plasma column, and R is the radius of the toroidal chamber and J_m is the maximum current of the discharge. With a decrease of the field to 2500 oersteds the first stage continues to exist to values of a current considerably exceeding those allowed by the criterion of stability given above.

(4) The mean conductivity in the column of the discharge in a magnetic field reaches (2 - 3) x 10^{14} CGSE to the moment of the transition of the first stage to the second.

(5) If the discharge current is kept up for a long time at a value lower than that allowed by the criterion of stability, then the conductivity reaches 6 x 10^{14} CGSE and then rapidly falls, probably due to the gassing of the walls.

"The authors are using the opportunity to express their thanks to T. P. Chupakhin and V. S. Vasil'evski, who constructed the apparatus and to A. K. Spiridonov who directed its preparation and its mounting.

V. I. Pistunovich: The Measurement of the Electron Temperature and Ion Concentration ~~in~~ by a Double Floating ~~Zone~~ Probe in an Electrodeless Discharge. (Work carried out in 1957); pp. 134-155.

This article contains ~~14~~ 15 figures and 3 tables, with a schematic of the apparatus, circuit diagrams, oscillographs, and graphical presentation of the results.

"The results of the work can be summarized in the following way:

(1) Determination of the value of the electron temperature, ion density, and the co-efficient of ionization of the discharge in a toroidal chamber for the condition U = 12 and 25 kv, p = 0.04 mm and external field equal to 0 obtained by the working up of the characteristics of a double floating probe zone having saturation.

(2) It is shown that the averaged electrical fluctuations in the plasma with the help of the small resistance in the circuit of the probes does not strongly affect the results of the temperature measurement of the electrons.

(3) The measurement of the electron temperature and of the ion density at different distances from the center of the chamber show that the determined parameters of the plasma change but little in the given cross section of the toroidal chamber.

(4) The parameters of the plasma do not change . . . in their dependence on the orientation of the double probe with respect to the axis of the chamber.

(5) The possibility is shown to apply the double floating probe for temperature measurement of electrons and ion density of the plasma for fields up to a thousand oersteds.

"In conclusion, the author thanks G. A. Egorenkov for help in making the measurements and A. L. Bezbatchenko and N. D. Klyuchnikov for the development and construction of the circuit for the generator of saw-tooth vibrations."

V. S. Strelkov: Investigation of the Radiation of an Electrodeless Discharge in Deuterium. (Work carried out in 1958); pp. 156 - 169.

This article contains 12 diagrams and figures and no tables.

"Experiments are described on the investigation of the radiation of an electrodeless pulse discharge in the visible and X-ray part of the spectrum. The X-rays are formed due to the decceleration of rapid electrons in the target material or on the walls of the discharge chamber. The region of origin and the average energy of the rapid electrons is determined. The time dependence of the intensity of the spectral lines of deuterium and sillicon is determined in the visible part of the spectrum."

This work was carried out in the toroidal chamber described in this volume, page 116.

"The change in time of the spectral intensity of deuterium lines shows that at a certain moment of time there is a high degree of plasma ionization. The subsequent increase in the intensity of the spectral lines of deuterium is associated probably with the appearance of impurities from the wall of the chamber. The moment of the appearance of the impurities is not associated with the magnitude of the external magnetic field and is probably determined by the time of diffusion of the impurities from the chamber walls to the volume."

<u>D. P. Petrov, N. V. Filippov, T. I. Filippova, V. A. Khrabrov</u>: Powerful Gas Discharge in Chambers with Conducting Walls. (Work carried out in 1954 and 1957); pp. 170 - 181.

This article has 5 figures, including ~~a-sa~~ three scale diagrams of the apparatus.

"Results are described of the investigation of a pulse gas discharge in a straight two-electrode chamber with conducting walls. A difference of processes of formation of the discharge compared to that with ceramic walls is established. The pulsed neutron emission has been discovered and investigated in a large range of gas pressures. (0.02 to 60 mm, 85 to 145 mkf, 100 to 600 k ampere, and rise time of current ~~for~~ 4×10^{10} to 2×10^{11} a second.) It is shown that the source of the neutron emission is localized in the pre-anode region of the discharge."

<u>A. M. Andrianov, O. A. Bazilevskaya, Yu. G. Prokhorova</u>: Investigation of the Pulse Discharge in Deuterium for Velocities of Current Rise of up to 10^{12} amp/sec and Potentials to 120 kv. (Work carried out in 1957, 1958); pp. 182-200.

There are 15 figures and 2 tables with a scale diagram of the apparatus.

"It is shown that for an initial potential greater than 80 kv, the duration of the neutron pulse increases significantly up to 2-3 microseconds. But that the duration of the pulse of the hard X-ray remains the same as for lower potentials (0.2 - 0.3 microseconds).

S. I. Braginski, I. M. Gel'fand, R. P. Fedorenko. The Theory of the Compression and Pulsation of a Plasma Column in a Strong Pulse Discharge. (Work carried out 1957-58); pp. 201-221.

"An investigation has been made of the magneto-hydrodynamic problem of the compression and the pulsation of a plasma column. A system of equations with partial derivatives which describe the column, together with the electrical engineering equations for the discharge circuit, were numerically integrated on an electronic calaculating machine. The results of the calculation were compared with experimental data. . . .

"We wish to express deep thanks to M. A. Leontovich for his initiative and help in the statement of the problem and many discussions."

The article is a theoretical one and contains 9 highly detailed graphs of the results of the calculations.

I. M. Podgorni, S. A. Chuvatin, G. A. Bikov, V. D. Pis'menni: Investigation of the process of electro-dynamic acceleration of clumps of plasma (II). (Work carried out in 1957); part I was published previously (L. A. Artsimovich, S. Yu. Luk'yanov, I. M. Podgorni, S. A. Chuvatin, Journal of Experimental & Theoretical Physics, 33, 3, 1957; pages 222-234.

This article contains 10 figures and 2 tables.

"This work contains an analysis of the experiments for determining the velocity and the size of the plasma clumps with the help of photo-electric methods. In addition to this, there is a comparison of the theoretically calculated curve of the current with that experimentally observed."

"An analysis of the current oscillograph gives for the mean velocity of the motion of the plasma clump a value of $(1.1 - 1.2) \times 10^7$ cm/sec."

E. E. Yushmanov: The Radial Distribution of Potential in a Cyclindrical Magnetic Trap Using a Magnetron Method of Ion Injection. (Work carried out in 1957); pp. 235-257.

This article contains 20 figures, including experimental arrangements.

"This article presents the results of investigations of the distribution of the potential along the radius in a cylindrical magnetic trap with magnetic mirrors and using a magnetron method of creating a plasma containing rapid ions. The potential distribution was measured in its dependence on the magnitude of the applied potential, magnetic field and other parameters. The measured potential distribution differed radically from the theoretical distribution corresponding to a non-compensated volume charge in the magnetron. Regular vibrations of the potential of the plasma were found under certain conditions with a frequency of 200-400 cycles per second. The amplitude of these vibrations was measured. . . .

"In conclusion, the author expresses his deep thanks to M. S. Ioffe for advice and suggestions."

There is a reference, among others, to Nodderman, Jour. Appl. Phys., 26, N 12 (1956).

V. I. Kogan: ~~Increas~~ The Widening of Spectral Lines in a High Temperature Plasma. (Work carried out in 1956-57); pp.258-304.

"In this article a theory is developed for the widening of spectral lines in an idealized plasma taking care (in the framework of a classical adiabatic model) of the simultaneous excitation of the emitting atoms by a large number of charged particles present in the heat discharge. General formulae were obtained for the distribution of intensity of the Stark component of the line widened because of the linear and quadratic Stark effect. These formulae have been simplified for the limiting cases of large and small densities and plasma temperature. The present shock theory was shown to be inapplicable to the widening produced by the linear Stark effect. The simultareous widening action of ions and electrons has been investigated. The form of the line for the simultaneous consideration of the Holtzmark and Doppler mechanism of widening has been found. The results (and likewise the role of several other mechanisms for widening lines) have been discussed as applicable to plasma of a massive pulse discharge in hydrogen."

B. A. Trubnikov: The ~~Connection~~ Relation between the Co-Efficients of Absorption and Emission of Plasma Radiation Present in a Magnetic Field. (Work carried out in 1957); pp. 305-308.

A short theoretical paper.

B. A. Trubnikov: The Behavior of Plasma in a Rapidly Varying Magnetic Field. (Work carried out in 1957 and partially reworked in preparation for printing in 1958); pp.309-330.

This is a long theoretical paper containing 13 figures.

"In this article an examination is made of the methods of thermal isolation and heating of a plasma with the help of external radpi rapidly varying magnetic fields. It is shown that by a suitable choice of the geometry of the field the clump of the plasma can be in equilibrium and therefore stable. The questions of heating the plasma are partially examined. . . .

"In conclusion, the author thanks N. A. Yavlinski for valuable discussions in this work."

A. I. Morozov: Cherenkov Generation of Magneto-Acoustical Waves. (Work carried out in 1958); pp. 331-352.

"An investigation has been made of the generation of magneto-acoustical waves in both limited and unlimited plasma. The source of the wave is considered to be contours with currents moving at high velocities. In the work of B. A. Trubnikov (page 309), using the hydrodynamic approximation, the problem of sound generation has been examined in compressible semi-bounded magnetized medium by excitation of pressures traveling along the surface.

"In high temperature plasma without a magnetic field the results obtained by Trubnikov are not applicable inasm;ch as sound cannot propagate in such a plasma because of the large magnitude of the mean free path of the ions.

"If inside of a plasma there is a magnetic field, then, as is well known, the dispersion equation contains a branch corresponding to magneto-acoustical waves. (cf S. I. Braginski, Dokladi, USSR, Ac. of Sc., Vol. 115, No. 3, 1957).

These waves are obtained both for large and for small mean free path of the particles, if the frequency of the wave is much smaller than the Larmor frequency of the ion. (cf. V. L. Ginzburg, Journal of Experimental Theoretical Physics, Vol. 21, 788, 1951.) If the frequency of collisions of ions with neutral particles is much larger or much sle smaller,/ than the frequency of the wave, then the magneto-acoustical waves decay weakly. Under these this condition, the magneto-acoustical waves, as is well known, can be described also by a system of magneto-hydrodynamic equations for an ideal liquid and we are using this fact in this article.

"The question of generation of magneto-acoustical waves has a definite interest in connection with the problem of heating the plasma and, likewise, in connection with working out the details of Gofrir magnetic systems inside of which the plasma moves."

B. B. Kadomtsev: Magnetic Traps for Plasma. (Work carried out in 1957); pp. 353-363.

"In this work a hydrodynamic investigation is carried out of magnetic traps. It is shown that systems with 'shielding conductors' are also magnetic traps, the losses from which are due basically to the suspensions. The presence of stability has also been established in ' traps with Gofrir field' . . . .

"I wish to express my thanks to Academician M. A. Leontovich for discussion of the work."

"There is a reference to the work of M. Rosenbluth, C. Longmire, Annals of Phys., 1, 120 (1957).

B. B. Kadomtsev: The Instability of Plasma in a Magnetic Field in the Presence of Ionic Beams. (Work carried out in 1958); pp. 364-369.

This is a theoretical paper.

"In some cases in the plasma there may be directed beams of ions. Thus, in the plasma 'of an ionic magnetron' created with the help of accelerating ions in a radial electric field, all ions undergo approximately the same periodic motion: moving in a radial direction they change the velocity direction under the action of a magnetic field and then at a certain point they turn around and return to the central region of the plasma. Such a motion leads to the formation of two beams of ions meeting each other in radial directions.

"An analagous situation may arise in the adiabatic trap with magnetic mirrors for the production of plasma by means of accumulation of ions from an ion source. Such a plasma occupies a ring region with a thickness equal to the diameter of the ion ring. But the ions again form two counter-currents in radial direction.

"As is well known, the electron beams in a plasma may be unstable. An analagous situation can take place in the given case.

"We are investigating in this article the instability of plasma with respect to short waved excitations, the wave length of which is much smaller than the mean Larmor radius of the ions." . . . .

"From this it is seen that the beam of ions in the plasma will be unstable if the scatter of ions in velocity is very small.

"We wish to thank Academican M. A. Leontovich for the discussion of this paper."

B. B. Kadomtsev: The Dynamics of Plasma in a Strong Magnetic Field. (Work carried out in 1958); pp. 370-379.

This is a theoretical paper with 5 references to foreign work of 1956, 1957, and 1958.

"In this work it is shown that for motion of the plasma, slow compared with the cyclotron frequencies of the ions, the motions can be described by the totality of equations of hydro-dynamics for the motion across the magnetic field and kinetic equations for the transverse motion. These equations can be simplified partially for the case of a plasma the pressure of which is much smaller than the magnetic pressure.

"Examination is made of the question of stability of the plasma of low pressure in a Gofrir field. . . .

"I wish to express my thanks for the discussion of the work to M. A. Leontovich."

B. B. Kadomtsev: The Convective Instability of a Plasma. (Work carried out in 1958); pages 380-383.

"This article investigates the instability of equilibrium magneto-hydrodynamic configurations with closed lines of force with respect to a definite form of perturbation."

R. S. Sagdeev: Non-Linear Motions of a Diluted Plasma in a Magnetic Field. (Work carried out in 1958); pp. 384-390.

"A solution has been found for established magneto-acoustical waves of large amplitude propagated across themagnetic field." . . . .

"We wish to thank Academician M. A. Leontovich and D. A. Frank-Kamenetski for interest in the present paper."

A. I. Morozov and L. S. Solov'ev: The Quenching of Vibrations of a Plasma Column. (Work carried out in 1958); pp. 391-414.

"Questions of quenching ~~ø~~ of vibrations of a plasma cyclinder with the help of different shields placed on the surface of the plasma ~~has~~ have been examined.

"The different cases of the vibrations of the plasma investigated in this work show that these vibrations can be quenched effectively with the help of a casing that has been picked in an appropriate manner. If the casing is a non-conducting material, the quenching takes places via the Cherenkov effect. For intensive quenching under the conditions of stability, it is necessary that the ratio of the distance of the plasma to the skin shielding to the dielectric permeability be several times ~~ø~~ 2 - 10 smaller than the period of the wave.

"If the casing is conducting, for effective quenching it is necessary that the skin layer corresponding to the frequency of the vibration of the wave be several times smaller than the above ratio.~~where-in-this-case~~

. . . .

"We noted that it is not necessary to quench the vibration with the help of a conducting layer; consequently, with the help of the Joule heating of this layer. One can also heat the waves with Cherenkov effect, at which the energy of vibration of the plasma is removed in the form of high frequency electro-magnetic waves.

"The remarks made above would appear to deal only with the stabilization of high frequency vibrations of the plasma. The slow 'creeping away' of the plasma column can be stabilized by internal fields of the type proposed by Osoevts (Vol. II, page 238) or by thick copper screening. The layer quenching the vibrations can be put on the internal surface of such a shield.

"Let us note in conclusion that the quenching layer may effectively iron out the turbulent electrical fields inside the toroidal chamber with copper cut casing and in this way serve as a liner if its vacuum properties turn out to be sufficiently good.

"The authors bring their sincere thanks to M. A. Leontovich for his useful discussion of the given article."

V. D. Shafranov: Deduction of the Tensor of Dielectric Permeability of a Plasma. (Work carried out in 1958); pp. 416-421.

"In the present note we have obtained by means of the integration of the kinetic equation a long the trajectories of charge, a general expression for the tensor of dielectric permeability of a plasma in the absence of collisions."

R. Z. Sagdeev: Absorption of Electro-Magnetic Waves Propagating along a Constant Magnetic Field in a Plasma. (Work carried out in 1958); pp.422-425 .

"An investigation is made of the question of the absorption of electro-magnetic waves in a plasma because of the thermal motion of electrons.

"It is of interest to analyze the mechanisms of the absorption of the energy of the plasma under conditions when one can neglect the collision of particles in pairs. This is particularly essential for high temperatures when the Joule absorption is sharply decreased and it is necessary to look for more effectively acting, under these conditions, mechanisms; and, in the first order, those not associated with colliding particles. . . .

"In the present communication we give solutions of the problem of the propagation of the electro-magnetic wave along a constant magnetic field without using the procedures of linearization, but neglecting the inner action of the magnetic field of the wave on electrons for sufficiently general initial conditions. This analysis can be considered as a particular case of the results of a linearized theory. . . .

"In conclusion, we would like to take this opportunity to express our thanks to Academician M. A. Leontovich and Prof. D. A. Frank-Kamenetski for valuable discussion and to V. D. Shafranov with whom we have discussed many times the questions touched in the present note."

There is a reference to T. Pradhan, Phys. Rev., 107,1222, (1957).

B. D. Shafranov: The Index of Refraction of a Plasma in a Magnetic Field in the Region of the Ion Cyclotron Resonance. (Work carried out in 1958); pp-426-429.

"In connection with the problem of dissipation of energy in a plasma in the absence of collisions, page 422, it is of interest to determine the conditions under which there is an absorption of energy of the electro-magnetic field by the particles of the plasma, (the range of frequencies, direction of the propagation of the wave field, etc.) for determining the region of absorption of the electro-magnetic field by the ions we calculate the square of the index of refraction of the plasma with consideration of the motion of the ions along the lines of force of the magnetic field."

R. Z. Sagdeev and V. D. Shafranov: The Vibrations of a Plasma Column with Consideration of the Heat Motion of the Ions. (Work carried out in 1958); pp. 430-435.

"As is well known, on increasing the temperature of a plasma the effectiveness of the usual Joule mechanism for heating drops. It is of interest to investigate other methods of heating of the plasma.

One of these methods is the 'betatron' method of heating, based on the periodic change of the magnetic field with a period comparable with the time of ion collisions.

"In the high temperature plasma in which collisions are rare it is interesting to investigate the mechanism of absorption of energy which are not associated with collisions. The physical basis of such non-collision (cyclotron and Cherenkov) absorption are discussed in Vol. IV, pages 422, 426, and Journal of Experimental & Theoretical Physics, 34, 1475, 1958. For a concrete calculation for the absorption of energy in a plasma column it is necessary to solve the problem of the vibrations of the plasma column. The vibrations of the cylinder of the plasma at frequencies considerably smaller than the cyclotron frequencies of the ions were investigated by Trubnikov, Vol. I, page 289, and Shafranov, Vol. II, page 130. The cyclotron resonance of ions was considered by T. Stix, Phys. Rev. 106, 1146, 1957, while the consideration of the high frequency vibration branches were carried out by K. Korper, Z. Naturforsch., 12a, 815 (1957), for the case of vibrations along the axis. All these eight cited articles were based on hydro-dynamic description of the plasma. Rudakov and Sagdeev

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~~L. I. Rudakov and R. Z. Sagdeev~~ solved the problem of the vibrations of a plasma column starting out from kinetic equations in the drift approximation, which considers heat motion of the ions along the lines of force of the field for frequencies less than the frequency of the internal magnetic field. Such an approach gives us a possibility to consider Cherenkov absorption.

In the present work a solution is given of the problem of the vibrations of a ~~svel~~ cylinder of plasma with consideration of the heat motion of the ions leading both to Cherenkov and cyclotron absorption."