DECLASSIFIED

UCRL 4795

MASTER

UNIVERSITY OF
CALIFORNIA

Ernest O. Lawrence

*Radiation
Laboratory*

LIVERMORE SITE

DECLASSIFIED

150 001

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DECLASSIFIED

~~SECRET~~

UCRL 4795

THIS DOCUMENT CONSISTS OF 29 PAGES
NO. 11 OF 15 COPIES, SERIES ~~1~~

ARC RESEARCH PROGRESS REPORT

Mirror Machine Program

October 15, 1956

Compiled by R. F. Post

Classification cancelled by authority of

SAN Office - memo dtd 9-17-58 J.W. Ruff, Class
on 10-30-58 by D. Howard Set - UCRL -
10-30-58

~~RESTRICTED DATA~~
This document contains restricted data as defined in the Atomic Energy Act of 1954. Its contents in any manner to an unauthorized person is prohibited.

1

150

002

~~SECRET~~
DECLASSIFIED

~~SECRET~~
DECLASSIFIED

UCRL 4795

TABLE TOP II

S. G. Zizzo, F. C. Ford

Operation of a high-energy ion source (5-10 KV) as developed by K. Ehlers of Berkeley has been attempted in Table Top. Visible evidence of source performance was obtained by allowing the beam to strike a cathode-ray type oscillograph screen. The source was developed in a d. c. field and performs well under such operation, but in an a. c. field of the type used in Table Top certain difficulties appear. The present problem appears to be one of breakdown in the extractor voltage system during a magnetic pulse.

A d. c. mirror test station has been developed to 'break-in' newly assembled sources prior to use in the pulsed field. In such operations the beam current has been measured by means of probes and it has been established that the positive ions are reflected by a magnetic mirror. The mirror ratio used for reflection (peak field divided by the source or injection field) was about 1.3. By use of the oscillograph screen technique parts of the reflected ion orbits have been observed as well as the transmitted orbits.

A magnetic analyzer (also an electrostatic analyzer) has been built for use in future experiments in Table Top to measure ion 'heating'. Single particle counting is employed for such work.

Some low temperature plasma injection is being planned for a larger diameter coil system for Table Top. In this system the vacuum envelope will approach the magnetic line configuration for the region between the mirrors in an effort to minimize wall effects. This system will also enable more satisfactory testing of ion sources of the Ehlers type.

~~RESTRICTED DATA~~

This document contains restricted data.
Its transmission or disclosure of its contents in any manner to an unauthorized person is prohibited.

~~SECRET~~

150 003

DECLASSIFIED

~~SECRET~~

UCRL 4795

FELIX

Frank Eby

Felix Vacuum Tank:

Work on the Felix main vacuum tank and pumping manifold is being vigorously pursued in the sheet metal shop in Berkeley. As of mid-October the job is estimated to be about 75 per cent complete. The final completion date, originally scheduled for early May, has been set as sometime in early November. The vacuum pumps are on hand, and the fore line system has been released for fabrication.

Area:

Shielding walls have been erected around the Felix area in Building 124, and the installation of a water manifold, air lines, electrical outlets, and other facilities is essentially complete. The difficulty which was encountered in the fabrication of a one ton crane, which was requested of plant engineering in early January, was rectified by removing the cross bracing and altering the truss cords in the roof over the area, and the crane has been in satisfactory operation since late August.

Electronics:

Electronic circuits associated with the pulsed operation of the magnetic field coils has been installed in the mezzanine adjacent to the area, and circuit debugging and testing has been in progress since July 19. A temporary coil having nearly the same electrical characteristics as the Felix coils has served as a load for test firings of the condenser bank. The component failures and defects which have been uncovered to date have been of a relatively minor, though sometimes rather time consuming nature. Thus far, there is no evidence that the basic circuits or important components are inadequate to the task, and there is reason to believe that within the next few months the system will be working reliably at full bank voltage.

As insurance against failure of the 'crowbar' chain, consisting of four series 5550 ignitrons, another chain of two 506 ignitrons, in parallel, has been installed and is nearly ready for testing. Current leads for d. c. operation of the coils were installed on the mezzanine in August and can be tested as soon as the coils are available.

Coils:

Work on the magnetic field coils, which was started in the coil shop in Building 124 on February 9 has taken somewhat longer than the originally anticipated two months. Winding of the coils is now complete and they are presently in the process of final machining in the shop in Building 114. It is estimated that they will be completed by December 15.

Sources:

Three different ion source arrays, all using occluded gas type sources, have been designed and are in various stages of fabrication and testing.

~~SECRET~~

150 304

~~SECRET~~

UCRL 4795

One arrangement, to be used in preliminary investigations of trajectories, mounts a single source on a support which can be positioned at various radii and axial positions near one mirror. This device has been built and is under test.

Another array mounts three sources at a fixed radius, spaced 120 degrees apart in an r, θ plane. Although provision is made for axial motion, the array must be removed from the vacuum system for alteration of the radial positions of the sources. Construction of this array is essentially complete. Tests on one of the source units indicate that about one ampere of 8-10 kev ions can be expected from the array.

A third system is still in fabrication. This system mounts six sources arranged on a six inch diameter circle in an r, θ plane. It will probably be several months before this system is operable.

Electrical apparatus associated with the sources has been built, but, as yet, not debugged.

Felix, Jr:

Following the successful hydrostatic testing (to 80 psi, radial load) of a full scale prototype section of corrugated tubing, the reaction chamber was designed and finished by late August. This chamber together with a vacuum manifold and six inch pump, Felix Jr., was assembled with fuse wire gaskets on September 21. To date, 28 small leaks have been found in the welds and have been patched, and the system (still without liquid nitrogen trap) has achieved a pressure of $1-2 \times 10^{-7}$ mm Hg. Upon the completion of a set of muffles, which is nearly finished, the system will be subjected to a limited bake-out at 160 degrees C. for the purpose of opening possible incipient leaks. After the repair of such leaks the system will be thoroughly cleaned, assembled with gold wire gaskets, and subjected to a 400 degree C. bake-out. Tests are presently under way to determine the optimum operating conditions of the diffusion pump and water baffle.

~~SECRET~~

PROGRESS REPORT 08

F. H. Coensgen, A. E. Sherman

A) Bank Performance

At the time of the previous report (UCRL 4705) banks one and two together with the control circuits for banks one, two and three had just been completed but not tested. These facilities have been tested and put into operation with less trouble than anticipated. The banks meet the original specifications with the exception of excessive inductance in bank one.

B) Vacuum System

To maintain the rather dirty but conveniently demountable system at sufficiently low pressures the pumping speed had to be increased. The four inch and six inch mercury diffusion pumps are being replaced by two ten inch mercury diffusion pumps which have been modified as recommended by H. Smith, for increased pumping speed. One unit has been installed and found to give excellent performance; however, an additional baffle is needed, and has been ordered, to keep the Hg from condensing on the liquid nitrogen trap.

C) Source

In the period of this report only the jet type source has been used. This source consists essentially of a reservoir of deuterium loaded titanium and a spark gap. An electric current is passed through the reservoir releasing deuterium which enters a spark gap through a hole in the grounded electrode. Typically, a 3.5 μ f capacitor charged to 20 kilovolts is discharged through the spark gap. A one ohm resistor is used to damp the electric oscillation. For the most part the reservoir has been small pieces of heavily loaded titanium contained in a one inch inside diameter glass tube; however, the gas output is not uniform from pulse to pulse. Recently a washer stack of one quarter inch inside diameter has been used as the gas reservoir and has given more uniform results. Further improvement may be achieved when the source potentials are carefully controlled.

The light from the source has been examined by spectrography and found to contain only hydrogen and carbon lines for a wide range of operating conditions. Since the last spectrographs were taken a number of structural changes have been made which completely eliminates all plastic exposed to the spark region. It is thought that these changes will decrease the carbon contamination.

D) Single Stage Transfer

In this setup the source was located in the 9 inch diameter volume about one meter from the end of the 9 inch pulsed field coil. The density was observed in the 3 inch volume by means of k-band microwave gear. Also some density observations were taken in the 9 inch volume by means of 8 mm μ -w gear. No trouble has been experienced in filling the 9 inch volume beyond densities of $10^{13} \frac{\text{ions}}{\text{cm}^3}$ which is more than adequate.

~~SECRET~~

UCRL 4795

Upon pulsing the 9 inch pulse coil, densities beyond 'cut off' ($\sim 10^{13}$) of the k-band μ -w gear were observed in the 3 inch volume. By varying the source parameters, delay times, field values, etc, the density in the 3 inch section can be varied. Observable densities remained in the 3 inch section with only a steady magnetic field for several hundred microseconds.

E) Multiple Stage Operation

At the time the ten inch pump was installed a set of high compression coils were installed on the 3 inch system. The first stage which is 18 inches inside diameter is currently being installed.

F) Diagnostics

Although the microwave measurements have been extremely useful they have a serious limitation in that rapid density variations cannot be followed. Thus it has been impossible to monitor the density during the 'filling' of any one volume. In a multiple stage experiment the only density which now can possibly be measured is the density after the final compression. However, results obtained by F. Ford in the Table Top experiment indicate that the present techniques are unreliable if the plasma filament is small. Further development of the μ -w techniques to overcome these limitations is certainly desirable.

Considerable evidence for electron heating has been obtained in past Toy Top and Table Top experiments. However, as the positive ion heating is the quantity of fundamental importance, the entire diagnostic effort of the $\phi\beta$ group is concentrated upon the development of a method to determine the energy of the positive ions which are scattered through the end mirror. The expected counting rate is such that individual events must be detected. A rather simple parallel plate electrostatic energy analyzer has been built using an electron multiplier from a Dumont 6292 photomultiplier as an ion detector. The performance of this instrument is being investigated with ions of known energy from a conventional ion source. In an exploratory run with a jet source it was found that the instrument must be shielded from the strong bursts of light and the plasma bursts which occur at the time the source is fired.

~~SECRET~~

~~SECRET~~

UCRL 4795

P⁴ SYSTEM

D. Edwards, N. Carlson, A. Gardner, L. Hall, W. Kilpatrick and H. Vandermark

I. Introduction

For a wide variety of investigations in pure and applied plasma physics, it would be very valuable to have a steady state source of plasma of density above, let us say, 10^{11} particles per cm^3 with a temperature of the order of a few electron volts. The present experiments are concerned with a particular proposal or set of related proposals of means for the production of such a plasma.

The natural environment to consider for the copious production of electrons and ions is a gaseous discharge; however, the properties of the plasma in the body of a steady state discharge are in general quite far from those we desire. In particular, the degree of ionization may be low, and while the electron temperature may be quite respectable, the ion temperature will be quite low. It has been suggested (J. Foster, R. F. Post) that one might obtain an essentially neutral-free plasma by allowing the charges from a discharge to diffuse along a magnetic channel away from the current carrying region. The neutrals may then be removed by differential pumping at the sides of the path which the charges are constrained to follow by the magnetic field. Under suitable conditions, the positive ions may gain energy from the electrons by Coulomb collisions, or other means of increasing the ion energy may be employed. We will return to this point later.

A tentative picture of a plasma source of the sort we envisage here then is the following. The first component is a steady state gaseous discharge whose primary function is the production of electrons and ions from neutral gas. As a secondary function, it is desired that the ion lifetime before leaving the discharge be sufficiently long that the positive charges gain energy from the hotter electrons by Coulomb collisions. An exit from the discharge is provided into a long differentially pumped tube with an axial magnetic field along which the charges may flow. The purpose of this tube is twofold; firstly, as mentioned above, it allows for the separation of charges and neutrals; secondly, means of increasing the plasma temperature (in particular, the ion temperature) over that obtaining in the discharge may be introduced. Finally at the end of the system, means must be provided for 'burying' the plasma so that neutrals formed at surfaces do not diffuse back into the experimental region.

II. The Discharge

The heating rate of a cold ion due to Coulomb collisions with a more energetic electron gas is given by⁽¹⁾

$$\frac{dW}{dt} = 1.4 \times 10^{-12} \frac{n_e}{T_e^{1/2}} \frac{\text{kv}}{\text{sec}} \quad (2-1)$$

where n_e is the number of electrons per cm^3 and T_e is the electron temperature in kev. Taking $n_e \sim 10^{14}/\text{cm}^3$ and $T_e = 10 \text{ ev} = 0.01 \text{ kev}$, one has

$$\begin{aligned} \frac{dW}{dt} &= \frac{1.4 \times 10^{-12} \times 10^{14}}{(0.01)^{1/2}} \sim 1400 \text{ kv/sec} \\ &= 1.4 \text{ volts}/\mu\text{sec} \end{aligned} \quad (2-2)$$

7
~~SECRET~~

150 008

~~SECRET~~

UCRL 4795

Assuming for the moment that an ion starts from rest and travels a distance s under the influence of an acceleration characterized by a constant dW/dt , the energy at the end of this path will be

$$W = \left(\frac{3}{2}\right)^{2/3} \left(\frac{M}{2}\right)^{1/3} \left(\frac{dW}{dt}\right)^{2/3} s^{2/3} \quad (2-3)$$

Taking $s = 10$ cm and the dW/dt computed in (2-2) gives for deuterons an energy of some 8 volts. This is of course not possible since the electron temperature was taken to be only 10 volts, however, it does suggest that a positive ion can gain energies in the several volt range by diffusing a reasonable distance within a discharge of the sort assumed.

Work performed by W. D. Kilpatrick on PIG type discharges with an open cathode suggests that a discharge having the desired properties can be constructed. Whereas the conventional PIG discharge has a cylindrical anode with two solid cathodes at either end, the sort intended here has one solid and one cylindrical cathode, as sketched in Figure 1. The open cathode provides the exit mentioned in Section 1, through which the plasma may enter the magnetic channel. The gas on which the arc is run is admitted through the other cathode.

Figure 1

That a positive ion retains its identity long enough to gain energy as described above is not known; this depends on details of arc behavior about which there is very little information such as neutral density at various positions in the discharge, the distributions of ion and electron energies and so on. That the plasma in a PIG discharge with an open cathode will flow through the opening appears clear from the experiments of Kilpatrick on small sources.

An open ended PIG discharge intended to test these principles has been constructed by Kilpatrick and Aplin. The arc diameter is 2 inches; the length may be varied by the introduction of various anode sections. The magnetic field is provided by several Albedo coils. At this writing, development is continuing to enable steady operation at the currents (30-50 amperes) required to establish charge densities of the order indicated above.

III. The Magnetic Channel

The first requirement that the magnetic channel must fulfil is the separation of charges and neutrals. While it is not possible to know the neutral

8
~~SECRET~~

150 009

~~SECRET~~

UCRL 4795

content of the plasma from the discharge beforehand, we may make a presumably pessimistic estimate. Let us assume that the neutral density at the exit of the arc is comparable to the density of ions. Note that in the event that it is necessary to operate the arc on a short pulse basis, this is just the requirement that would be imposed on the vacuum system, since before the arc was struck it would be necessary to reduce the pressure in the experimental region (where the plasma is to be used) to whatever was demanded, in general well below the pressure in the arc chamber.

The viscous conductance through a small aperture for air at 20° C. is⁽²⁾

$$C = 16D^2 \text{ liters/sec} \quad (3-1)$$

where D is the aperture diameter in cm. For D = 5 cm.

$$C \sim 16 \times 25 = 400 \text{ liters/sec} \quad (3-2)$$

If the pressure in the discharge region is some ten microns or so, we may then expect a gas flow into this region of the order of 10⁴ micron-liters per second. If we assume that the vacuum system consists of a series of modular units connected in series, the conductance of each one of which is approximately equal to its own pumping speed then five or six such sections should effect a sufficient pressure reduction to at least perform diagnostic measurements on the plasma. As we shall see shortly, diffusion considerations place further restrictions on the vacuum system.

Before discussing diffusion, it may be well to suggest a diameter for the magnetic channel. In order to reduce diagnostic difficulties and wall problems, large diameter systems are indicated. On the other hand, as one increases the diameter the magnetic field and pumping problems tend to become formidable. A six inch diameter system appears to be a good compromise; moreover, one can build up modular units of this diameter from readily available material.

Let us turn now to a brief consideration of how diffusion processes will effect the flow of the plasma along this magnetic field. There are three cross field diffusion processes which we should consider: (1) diffusion arising from electron-ion collisions, (2) diffusion arising from electron-electron and ion-ion collisions, and (3) diffusion arising from collisions of charged particles with neutrals.

The cross field diffusion velocity due to electron-ion collisions is given by Spitzer⁽³⁾ as:

$$v_{\perp 1} = - \frac{\eta}{B^2} \nabla p = - \frac{1.29 \times 10^{13} Z \ln \Lambda}{B^2 T^{3/2}} \nabla p \frac{\text{cm}}{\text{sec}} \quad (3-3)$$

where T is in degrees Kelvin and B in gauss. Setting $p = nkT$, $T = 12000 \text{ T}_{\text{ev}}$, $Z = 1$ and $\ln \Lambda = 20$, we have

$$v_{\perp 1} = - 3.3 \times 10^{-4} \frac{\nabla n}{B^2 T_{\text{ev}}^{1/2}} \frac{\text{cm}}{\text{sec}} \quad (3-4)$$

where T is now in electron volts. If we take B = 500 gauss, T = 10 ev, and

~~SECRET~~

$V_n \sim 10^{12}$ particles per $\text{cm}^3/10 \text{ cm}$, one obtains,

$$v_{\perp 1} = 40 \text{ cm/sec} \quad (3-5)$$

Since a 10 volt ion will have a velocity along the channel of the order of 10^6 cm/sec , the cross field velocity given by (3-5) is negligible.

The cross field diffusion velocity due to like particle collisions has been computed by Simon⁽⁴⁾, who finds:

$$v_{\perp 2} = \frac{3}{8} \frac{r_o^4}{\tau} \frac{1}{n} \left(\frac{d^3 n}{dx^3} - \frac{1}{n} \frac{d^2 n}{dx^2} \frac{dn}{dx} \right) \quad (3-6)$$

where $r_o = mvc/eB$ is the Larmor radius, $\tau = \lambda/v$ is the mean free time between collisions and x is a position variable measured across the field. Let us assume a distribution of the form

$$n = n_o \left[1 - \frac{r^2}{a^2} \right] \quad (3-7)$$

Then

$$v_{\perp 2} = -\frac{3}{2} \left(\frac{n_o}{n} \right)^2 \left(\frac{r_o}{a} \right)^4 \frac{r}{\tau} \quad (3-8)$$

Taking $n_o/n \sim 2$, we may write (3-8) in the form

$$v_{\perp 2} = -\frac{0.9 n_+ T_{ev}^{1/2}}{B^4} \frac{\text{cm}}{\text{sec}} \quad (3-9)$$

where we have set $r_o = \frac{144}{B} T_{ev}^{1/2}$, hence have specialized the result for the particular case of protons. We see again that this diffusion velocity is too small to be of any concern. The electron-electron diffusion rate is of course much smaller.

The diffusion coefficients for ions and electrons colliding with neutrals are given by Simon⁽⁵⁾ as

$$D_{+13} = \frac{D_+^0}{1 + (\omega_+ \tau_+)^2} \quad (3-10)$$

$$D_{-13} = \frac{D_-^0}{1 + (\omega_- \tau_-)^2}$$

where $\omega_{\pm} = eB/m_{\pm} c$

$$D^0 = \lambda v/3 \quad (3-11)$$

Here λ is the mean free path for collisions with neutrals. We may neglect the one in the denominators of (3-10) and rewrite them in the form

~~SECRET~~

UCRL 4795

$$D_{+13} = \frac{v_+ r_{o+}^2}{3\lambda_{o+}} \quad (3-12)$$

and

$$v_{+13} = D_{+13} \frac{1}{n} \nabla n \quad (3-13)$$

Taking again the special case of protons:

$$\begin{aligned} v_{+13} &= \frac{v_+ r_{o+}^2}{3\lambda_{o+}} \frac{\nabla n}{n} \\ &= 3 \times 10^{-3} \frac{n_o}{B^2 T_{ev}^{1/2}} \frac{\nabla n}{n} \frac{\text{cm}}{\text{sec}} \end{aligned} \quad (3-14)$$

where n_o is the neutral density. The diffusion velocity for electrons will be smaller by the square root of the mass ratio. For a neutral density of $10^{12}/\text{cm}^3$, corresponding to a base pressure of about 3×10^{-5} mm of Hg, and $T_{ev} = 1$ volt, $B = 500$ gauss:

$$v_{+13} = 10^3 \text{ cm/sec.} \quad (3-15)$$

The diffusion produced by collision of ions with neutrals is thus seen to be the one which can cause trouble in this sort of system.

Since the neutral pressure leading to this diffusion may arise from plasma diffusing to the walls and becoming neutralized, it is of interest to relate this neutral production to the pumping speed of the vacuum system. Let us suppose now that the vacuum system for the magnetic channel consists of a series of identical units each a meter in length and let the pumping speed out of this meter length of pipe of volume be S . Then

$$\frac{dp}{dt} = \frac{Q}{V} - \frac{pS}{V} + \frac{Q'}{V} \quad (3-16)$$

where Q is the neutral source arising from ion diffusion to the walls, p the neutral pressure, and Q' the 'leak' source of neutrals which may stem from various causes: e.g., (a) axial diffusion of the neutral particles from the discharge region, (b) outgassing of particles from the walls or (c) the axial diffusion of neutral particles created by the neutralization of ions in other portions of the channel. If one assumes that the contribution from cause (c) is negligible then if the plasma is absent but the neutral flow into the channel is assumed to be unchanged the 'base pressure' is given by:

$$p_o = \frac{Q'}{S} \quad (3-17)$$

11
~~SECRET~~

150 012

~~SECRET~~

UCRL 4795

We may make an approximation to Q by assuming that every ion which strikes the wall returns as a neutral particle. Then if A is the wall area of the meter length of system

$$\begin{aligned} Q &= \frac{n_+ v_{\perp} A}{3 \times 10^{16} / \mu \text{ liter}} \\ &= 3 \times 10^{-3} \frac{n_0}{B^2 T_{ev}^{1/2}} \frac{A v_{n+}}{3 \times 10^{16}} \\ &= \left[2 \times 10^{-3} \frac{n_+}{B^2 T_{ev}^{1/2}} \right] p \end{aligned} \quad (3-18)$$

In the last form of (3-18) we have limited ourselves to the case of a 6 inch diameter system, and have taken v_{n+}/n_+ to be $n_+/10$ cm. Q is measured in micron liters per second in these formulae. If we define

$$S^* = 2 \times 10^{-3} \frac{n_+}{B^2 T_{ev}^{1/2}} \quad (3-19)$$

we may rewrite (3-16) as

$$\frac{dp}{dt} = -\frac{p}{V} (S - S^*) + \frac{p_0 S}{V} \quad (3-20)$$

If S and S^* are independent of pressure^(a) we may integrate (3-20) and obtain

$$p = \frac{p_0}{\left[1 - \frac{S^*}{S} \right]} + A e^{-\frac{(S-S^*)}{V} t} \quad (3-21)$$

where A is a constant determined by the initial conditions. For example if $p(t=0) = p_0$,

$$A = p_0 \frac{-\frac{S^*}{S}}{1 - \frac{S^*}{S}} \quad (3-22)$$

$$p = p_0 \frac{\left[1 - \frac{S^*}{S} e^{-\frac{(S-S^*)}{V} t} \right]}{1 - \frac{S^*}{S}} \quad (3-23)$$

From (3.21) we see that unless S is greater than S^* , the feedback in the loop which makes neutrals out of ions and so causes more diffusion to make more neutrals will be too great and the pressure will build up. Actually such a buildup would cause n_1

(a) The ion density, n_1 , and hence S^* will of course depend on p and also on the position along the channel. If one assumes that the discharge is not affected by the pressure in the channel then n_1 at the input to the channel will be constant and the following equations would then apply for that position.

~~SECRET~~

150 013

~~SECRET~~

UCRL 4795

and hence S^* to be reduced and could in effect increase S (or alter p_0) because of the influence of axial pressure gradients. Equilibrium would be reached with effective final values $S^* < S$. When S is greater than S^* , the equilibrium pressure, which will always exceed p_0 , is given by:

$$p = \frac{p_0}{1 - \frac{S^*}{S}} \quad (3-24)$$

Finally, the relaxation time for these effects is (from the exponential term in (3-21))

$$\tau = \frac{V}{S - S^*} \quad (3-25)$$

In order to get some numbers out of these expressions, let us take $S = 2000$ liters/sec. Then the maximum ion density that can be sustained, i.e., taking $S^* = S$, is:

$$n_+ = B^2 T_{ev}^{1/2} \times 10^6 \quad (3-26)$$

According to (3-26) it requires a field of 1 kilogauss to retain a 1 ev plasma having an ion density of 10^{12} per cm^3 in a system with a pumping speed of 2000 liters per second per meter length. These considerations, approximate though they are, emphasize the need for high pumping speed in systems of this sort, quite independently of the base pressure requirements.

The relaxation time (3-25) is also of interest. For an order of magnitude lower limit if we take $S^* = 1/2 S = 1000$ liters per second and V that for a cylinder 1 meter long and of 6 inches diameter, we obtain $\tau \sim .02$ seconds. This is a comparatively long time and suggests that in pulsed applications one may be able to exceed the limitations indicated above. Of course, measurements intended to test the accuracy of equilibrium pressure predictions must be taken after times long compared with the relaxation time.

(3-19): The limiting ion density may be rewritten in terms of $\beta = \frac{nkT}{B^2/8\pi}$. Using

$$\begin{aligned} S^* &= \frac{2 \times 10^{-3} n_+}{B^2 T_{ev}^{1/2}} = \frac{10^{-3} n}{B^2 T_{ev}^{1/2}} \\ &= \frac{1}{2 \times 10^{-8} T_{ev}^{3/2}} \beta \end{aligned} \quad (3-27)$$

or, since $S^* < S$,

$$\beta < 2 \times 10^{-8} T_{ev}^{3/2} S \quad (3-28)$$

For $S = 2000$ liters per sec. and $T_{ev} = 1$ ev, $\beta = 4 \times 10^{-5}$. At $T_{ev} = 10$ ev, β is up to 0.1 per cent.

The magnetic channel currently being constructed under the direction of N. Carlson is intended to approximate the conditions of the preceding pages. The

~~SECRET~~

~~SECRET~~

UCRL 4795

plasma path is provided by a series of 6 inch diameter glass crosses. Each of the arms of the crosses transverse to the direction of motion of the plasma is connected to a 6 inch oil diffusion pump through a glass tee or elbow. This arrangement provides 4 diffusion pumps per meter of path, which should provide a pumping speed close to 2000 liters per second. Space considerations as well as the requirements of high pumping speed suggested initial operation without liquid nitrogen trapping. The magnetic field is provided by π -coils which alternate with pairs of pump arms. Since the pump arms require an 18 inch spacing of the coils, the coil radius is chosen to be 18 inches in order that the magnetic field be reasonably uniform along the axis. An array of coils separated by their radii will have a ripple of the order of 5 per cent in axial field. The present arrangement allows fields up to 1000 gauss, by stacking four π -coils at each position. Thirty-two of the basic pi's have been ordered, each consisting of sixteen turns of 3/4 inch square copper conductors wound on a 36 inch average diameter with a 6 inch build up. (There are thus two layers of conductors, each eight turns deep.) Water cooling is provided by a 3/8 inch hole through the center of the conductor. To date, eight of the pi's have been delivered. While there are other more elegant ways of designing a system of this sort, it was felt that an assembly of modular units each constructed of standard parts would provide the most flexible system with which to begin this investigation.

I. 'Present Intentions'

The first order of business once the arc and the first few sections of the magnet channel are assembled will be to attempt to measure the density and temperature of the plasma flowing from the discharge, as well as the dependence of the density on the distance along the channel. The density can be measured by microwaves, and the ion temperature obtained, hopefully, by introducing some helium and looking at the Doppler broadening of the $4686 \text{ \AA}$ line of singly ionized helium. These two measurements and their dependence on arc conditions should give one a pretty fair idea of the feasibility of making a useful plasma source employing this scheme.

In the event that the ion temperature is too low to be useful, additional means of heating must be provided in the magnetic channel. Gardner and Hall have investigated the feasibility of one method employing magnetic pumping at several locations along the magnetic channel, and preliminary design work is being done to incorporate this into the system.⁽⁶⁾

It would be desirable to remove the limitations on ion density and hence on β imposed by the diffusion arguments of the preceding section.. It appears that with appropriate re-design of the magnetic field this will be possible by effectively removing charges which are about to strike the walls, i.e., by employing the diverter action which has been utilized in Stellarator design. It should also be mentioned in connection with the diffusion arguments that the existence of shorting currents is assumed. If these do not occur, then the situation is considerably better. The plasma 'burial' problem at the end of the system can also be greatly improved by a suitable shaping of the magnetic field in that region.

~~SECRET~~

~~SECRET~~

UCRL 4795

References:

1. R. F. Post, Rev. Mod. Phys. 28, 338 (1956)
2. Guthrie and Wakerling, 'Vacuum Technique', McGraw-Hill
3. L. Spitzer, Jr., 'Physics of Fully Ionized Gases', Interscience, 1956, Page 38.
4. A. Simon, Phys. Rev., 100, 1557 (1955)
5. A. Simon, Phys. Rev., 98, 317 (1955)
6. Hall, Gardner, and Edwards, UCRL 4752

~~SECRET~~

~~SECRET~~

UCRL 4795

CONTAINMENT TIME OF β PARTICLES IN THE MIRROR MACHINE

Gordon Gibson, John Howard, Eugene Lauer

It is planned to use Ne^{19} (2.3 Mev end point β^+ , 18 second half life) for this experiment. The Ne^{19} gas will be produced by (p,n) reactions on F^{19} by bombarding MgF_2 powder with protons from the Livermore 90 inch cyclotron. The MgF_2 will be bombarded in vacuum with the protons entering through a thin foil, and part of the Ne^{19} atoms produced inside the MgF_2 powder will diffuse out of the powder (before decaying) into the volume of the bombardment chamber. Part of these atoms in turn will random walk through the long pipe from the bombardment chamber to the mirror machine which will be located just outside the cyclotron shielding wall. The bombardment chamber and 70 foot long 2 inch diameter pipe line have been constructed and are being tested using a small preliminary vacuum bench in the place where the mirror machine will eventually be located. The purpose of the preliminary test is to see if the conditions necessary for the final mirror machine experiment can be achieved, namely:

- (1) Can we produce enough activity to give good counting statistics in the mirror machine experiment, (1000 counts/second in a β ray energy interval of 1 ± 0.1 Mev would make a good experiment).
- (2) The total pressure in the closed system (diffusion pump cut off) should be maintained at 5×10^{-6} mm Hg or less, the pumping being done by a getter (outgassed, liquid nitrogen cooled charcoal) which pumps on the main gases contributing to the pressure but does not pump appreciably on neon. (The neon partial pressure will only be about 10^{-11} mm Hg).

One run has been had with the preliminary apparatus with the result that $10 \mu\text{a}$ of 13 Mev protons were passed through the $\sim 10^{-3}$ inch thick Ta foil and based on the resulting steady state counting rate, we would predict 60×10^3 counts/second of 1 ± 0.05 Mev β^+ in the final experiment. The pressure in the closed system was $\sim 3 \times 10^{-6}$ mm Hg with the beam off but rose to many microns when the beam was turned on the target, probably due to fluorine gas released by decomposition of MgF_2 . A series charcoal trap has been constructed and it is hoped that this trap will stop enough of the impurity gas and still pass enough Ne^{19} . A detailed report on the plans for this experiment will soon be written.

~~SECRET~~

SATURN EXPERIMENT

D. F. Martin and M. M. Hill

A new set of coils has been made for Saturn, along with a modification of the coil mounts, which allows rapid interchange of different coils. The new coil set is a nominal 6 inches in diameter with 6 turns each, and spaced 6 inches apart. In conjunction with 'ox cart' this gives a rise time of approximately 50 μ sec and a maximum magnetic field between the coils of nearly 15 kilogauss. The new coils and modified mounts have been installed on Saturn and tested and found to be satisfactory.

The Saturn machine is now operating and the previously reported¹ diagnostic techniques are being repeated to determine if any changes of the observed experimental results vary with the change in rise time and peak magnetic field value.

The increased central luminosity or 'central ball of light' is still observed with, what appears to be, a smaller final diameter. Preliminary microwave noise power measurements have been made. In conjunction with the above methods, a new technique is being applied. A contaminant gas (argon or helium) is introduced at various pressures (varying from 10^{-3} to 10^{-6} mm Hg) to determine their effect on the electrons temperature represented by the R. F. noise and the effect of the cold contaminant gas upon the luminosity of the 'central ball' and its formation. Spectrographic measurements of the contaminant gas are also being made.

1. D. F. Martin and M. M. Hill, UCRL 4705

~~SECRET~~

~~SECRET~~

UCRL 4795

Progress Report

Bill Lamb

I. Ion Source Development

On the small ion source 500 ma. unanalyzed on a duty cycle of 3 m.s. pulses once per second.

A gas pulser consisting of a solenoid valve and appropriate gate on delay controls was operated in connection with the small ion source and was quite successful in reducing the operating pressure of the system to the low 10^{-6} mm range.

A new vacuum system is being designed using an existing pumping and manifold for use with the large ion source which is being prepared for trial in the present system.

II. Guppy III

The ion pump conversion was completed and some preliminary experiments have been run. No significant results yet.

III. Waldo

The construction of 'Waldo' as presently conceived is postponed until further developments indicate a better chance of success in obtaining information that is commensurate with the cost.

~~SECRET~~

PROGRESS REPORT

(W. I. Linlor)

A. Photo-Dissociation Work

The writer returned on October 1, 1956 from a five-month stay at Oak Ridge, where measurements were made with C. F. Barnett and Richard Reinhardt of the photo-dissociation cross-section of H_2^+ ions. The measured average value for 100 KV ions irradiated by a G. E. AH-6 (high pressure, 1,000-watts) mercury vapor lamp was 10^{-17} cm², which is close to the value calculated by the writer of 3×10^{-18} cm². (This same value was also later independently calculated by Gordon Gibson.)

B. Beam Inflection Results

An experiment was completed by the writer with the help of Charles Lacy just before leaving for Oak Ridge, but because of the absence, the results were not included previously in these progress reports.

A beam of 20 milliamperes of 100 KV H^+ ions was passed perpendicular to a magnetic field of about 400 gauss, by the aid of a 'crossed' electric field. The beam angular divergence was less than 0.01 radian. No blow-up, charge-separation, or similar deleterious effects were noticed. Photographs were taken of the pattern made by the beam on tungsten sheets, showing actual concentration of the beam for certain conditions.

~~SECRET~~

UCRL 4795

HIGH VACUUM

J. R. Ullman, Norman Milleron, R. E. Ellis

Testing of various types of metal gaskets on the 20-inch test flange system has continued under conditions of high vacuum and thermal recycling. Temperatures of $\sim 400^{\circ}\text{C}$ and higher have been used on all the components of the system, exclusive of pumps, for bake-outs. Because of lack of definitive results in the continued thermal recycling of copper o-ring gaskets, and the imminence of the assembly of Felix Junior, N. Milleron suggested that a high vacuum seal, which would withstand repeated bakeouts, might be obtained by using indium metal as a liquid sealing agent during bakeouts, in conjunction with copper gaskets.

Accordingly, a first attempt was made using annealed 60-mil double copper wire gaskets (OFHC), with pump out space between, the inner gasket and flange surfaces being tinned with cerro-seal (50 per cent tin - 50 per cent indium). After one bakeout cycle, this system leaked, and there was considerable evidence that the tin component of the Cerroseal had attacked the stainless steel flanges and the copper gasket sufficiently to cause pitting and consequent large leak paths.

A test was successfully completed using 20-mil annealed OFHC copper o-ring gaskets, with inner gasket and flanges tinned with pure indium. A pressure in the 10^{-7} mm Hg range was attained but because no clean Alpert baffles were available, no lower pressure was reached. Three thermalcycles at temperatures reaching 425°C were completed with no detectable leaks. A leak in the indium seal was subsequently produced when an attempt was made to restore the torque on the flange fastenings to their pre-bakeout value after the third bakeout. It was not possible to reseal this leak by heating the flanges to $\sim 400^{\circ}\text{C}$ -- well above the indium melting point ($\sim 160^{\circ}\text{C}$). No further tests of indium seals have been made. It was necessary to have the flanges re-machined to remove channel depressions caused apparently by insufficient annealing of the copper gaskets and not by any reaction of the indium with the stainless steel.

The liquid nitrogen-cooled re-entrant trap, designed for use on Felix, was assembled (without the designed heat shields) and tested. After the repair of a weld leak and re-designing of the ion gauge flange (too thin, with no compliance in the fastenings), the trap was baked out for about two days. A base pressure, after cooling, of a little less than 10^{-8} mm Hg. was attained without liquid nitrogen. After filling, the pressure stabilized at $\sim 5 \times 10^{-10}$ mm Hg. It was found that the trap would maintain this low base pressure for ~ 5 hours with one filling. With regular 2-3 hour fillings, the trap maintained essentially this pressure over a 6-day period, after which time additional thermal recycling was resumed in order to determine the ability of the metal gasket seals to withstand repeated heating and cooling. The system had been assembled with double 16-mil annealed gold gaskets on one set of flanges and double 20-mil OFHC annealed copper gaskets on the other set. The gaskets were about 8 inches in diameter. A single 15-mil annealed gold gasket provided the ion gauge flange seal. After four thermal cycles in which all components were heated to $\sim 450^{\circ}\text{C}$, there were no detectable leaks in any of the gold gaskets at a system pressure of $\sim 6 \times 10^{-10}$ mm Hg. There were no leaks in the copper gaskets until the fourth bake-out at which time a leak appeared in the inner copper gasket. Since the outer copper

~~SECRET~~

~~SECRET~~

UCRL 4795

gasket was still tight, by pumping between the gaskets to ~ 10 microns Hg, the system pressure remained at $\sim 6-8 \times 10^{-10}$ mm Hg. With the gasket interspace at atmospheric pressure, the system pressure would rise to $\sim 10^{-5}$ mm Hg. This leak was made worse by increasing flange compression. The torque on the fastenings for the copper gasket seal remained essentially at 20 lb. ft. throughout the four bakeouts. The torque on the fastenings for the gold gasket seal increased from the initial 30 lb. ft. to about 45 lb. ft. average after four bakeouts. No additional torque was applied at any time during the thermal cycling.

From our total experience in these tests it might be concluded that the small wire-diameter gold gaskets offer the most reliable method of obtaining tight metal vacuum seals capable of surviving several high-temperature bakeouts. For the wire diameter used here, the cost of even large gaskets is nominal, annealing may be done in an ordinary furnace, and the flame welding is not difficult. Further tests of larger gaskets will be made on the 20-inch test flanges.

A test chamber (volume ~ 8.5 liters) has been assembled on one of the test stands and is being vacuum tested preparatory to use for testing such ultra-high vacuum system components as a metal-ceramic high-current conductor lead-in, porcelain enamel-coated heaters for use in bake-outs, as well as for the comparative calibration of Veeco and Bayard-Alpert ion gauges at very low pressures. Also contemplated is the development of a bake-outable system for measuring pumping speeds at low pressures.

Some work has been done on the problem of developing some techniques and materials for the purpose of using porcelain enamel as an ultra high vacuum 'glue', with some success in sticking conducting wires to stainless steel plates which will hold several KV between wire and plate (voltages up to ~ 30 KV are contemplated as possible). Here the attempt is made to obtain good insulation with fairly thick coats (30 mils or more) of porcelain enamel along with good high vacuum characteristics at elevated temperatures and high bonding strength. Also, the high vacuum characteristics of ceramic coatings applied to stainless steel may be investigated in this set up.

A demountable high voltage lead-in has been tested for F. Eby by Pat Fitzgerald on one of the test stands and found to function satisfactorily through several bakeouts. This is a glass-kovar type of insulated vacuum seal and the demountable seal consisted of a 30 mil annealed gold o-ring gasket compressed with a small stainless steel flange to which the glass kovar insulator was welded.

21
~~SECRET~~

150 022

VACUUM TECHNIQUES

N. Milleron

Primary Objectives:

I. To develop a vacuum pump for hydrogen isotopes with a gas handling capacity commensurate with the injection of many amperes of ions or fast neutral particles in high vacuo.

II. To develop pumping techniques for rapidly attaining ultra high vacua in non-kinetic systems.

Note: Perhaps I and II can be satisfied by different uses of the same basic approach.

Work on Objective I:

A. Evaporation of titanium from its liquid state has been done by electron bombardment. Referring to Figure 1, titanium wire is fed up through the center of a water cooled copper tip. As the wire extends above the tip, it draws more and more current from the tungsten filament, finally forming a molten ball held in place by surface tension just above the tip. If the molten ball touches the tip, so little heat is transferred at the discrete points of contact that no difficulties have been encountered. Evaporation from the molten ball then takes place, the rate of feed of the wire being matched to the power input.

Interestingly, the molten ball will 'explode' if continuously heated faster than its accumulating heat energy can be dissipated by evaporation. Under continuous heating, the molten ball 'explodes' into fragments; however, if pulses of energy of sufficient intensity are delivered to a thin 'skin' on the molten surface, the ball may be 'peeled' before an 'explosion' can occur. Sixty cycle voltage between electron emitter and ball super-imposed on D.C. produces the desired pulse effect. Figure 1 shows a cross-section of this water cooled tip evaporator.

B. A vacuum arc may be struck using the same tip and a tungsten electrode as shown in Fig. 2. Accordingly, Figures 1 and 2 are combined in proposed application.

C. A high current vacuum arc between titanium electrodes was run using Frank Eby's electrode design, vacuum tank and magnetic field. Frank was interested in the space charge neutralization possibilities of the radiation from the arc while I wished to consider the vacuum arc as a means of evaporating titanium. Arc ran at ~ 50 volts and ~ 300 amperes for a few times not longer than one second each until failure of a water cooled insulator ended the effort.

Work on Objective II:

A. Using Frank Eby's vacuum tank again, a cold cathode P.I.G. type discharge was run observing that:

1. A 100 gauss magnetic field will run a cold P.I.G. type discharge between 1 1/4 inches diameter plane parallel cathodes inside a cylindrical anode. The discharge achieved stability only at 200 gauss or more.

~~SECRET~~

~~SECRET~~

UCRL 4795

2. A pumping effect was detected when silver was evaporated onto the copper cathodes. This pumping effect was almost masked by the rapid outgassing of the tank wall which was the anode. An equilibrium was established at $\sim 1 \mu$, 300 mils, 4 KV and 200 gauss between the rate of outgassing from the walls and the pumping action due to ions 'sticking' in the silver being plated on the cathodes.

B. A sample of 'pure' indium was heated to the softening point of pyrex glass in vacuo and was visually observed to evaporate slightly at this temperature. A sample of 'pure' tin similarly heated showed no visible evidence of evaporation.

C. A marriage of 'surface tension sealing' and wire gaskets was tried using Indium on copper. Results reported elsewhere. Use of stainless wire in place of wire that is attacked by Indium at elevated temperatures was suggested.

D. Work on easily constructed flanges, valves, and 'introduced motions' utilizing the surface tension of liquid indium is being done in Berkeley at the student shop in Building 80.

E. A valve using a thin stainless diaphragm disk and the surface tension of liquid indium to seal against atmospheric pressure is ready for testing.

F. Consulted R. Gomer of University of Chicago about cryogenic pumping of hydrogen. He has evidence to indicate the boiling temperature of liquid helium is not low enough to 'freeze out' para hydrogen. Gomer also confirmed the limiting character of titanium hydride with respect to base pressures.

G. Referring to Fig. 3, construction of a hot cathode P. I. G. pump using tip evaporator (Figures 1 and 2) has begun. Evaporation of molybdenum, tantalum, and tungsten will be tried. Advantages of these metals over titanium may be:

1. No hydride formation?
2. Complete pre-outgassing of these metals is possible before evaporation occurs in good vacuum.
3. All three, Mo, Ta, and W getter certain gasses very well.

May attention be called again to the pumping action of the Westinghouse 5966 ion gauge and the low pressures attained? As shown at Harvard, this gauge will not pump when the inside of its glass envelope is completely clean (free from any metallic layer). Pumping action occurs when the evaporated layer of tungsten which is cast by the hot filament is established. The tungsten, in my opinion, forms a matrix for accelerated ions to 'bury' themselves in. The role of gettering by tungsten in the 5966 gauge remains to be clarified.

~~SECRET~~

~~SECRET~~

UCRL 4795

Bombarding Filament
.030 inch diameter Tungsten Wire

3 KV D.C. Potential with 2 KV
60 Cycle Ripple Applied Between
Ball and Filament

CROSS-SECTION
OF
WATER COOLED
EVAPORATOR TIP

FIGURE 1

~~SECRET~~

~~SECRET~~
VACUUM
ARC
EVAPORATOR

UCRL 4795

D.C. or A.C. Potential
Between Tungsten anode
and cathode of <
approximately 60 volts.
Arc Current < 50 Amps.

Water cooled Tip to
support metal which is to be
deposited on walls of pump.

Vacuum Arc struck between Tungsten anode and refractory metal cathode. Contact between electrodes in vacuo is normally closed. Arc is established when the solinoid is activated by pulling the electrodes apart. When Arc goes out, electrodes close, and cycle is repeated. The vacuum arc is sustained on metal 'gas' coming primarily from cathode.

FIGURE 2

~~SECRET~~

UCRL 4795

CROSS-SECTION OF P.I.G.
PUMP WITH HOT CATHODES

Figure of Revolution

INDICATED POWER REQUIREMENTS:

Discharge Current - 1 Amp. at 2000 volts	2000 Watts
Hot Cathode Power - 30 Amps. ~ 5 volts	150 Watts
Magnet Power < -	500 Watts
Bombarding Filament Power - 30 Amps ~ 4 volts	120 Watts
Maximum Bombarding Power - <.08 Amperes < 10 KV	< 800 Watts
Feeder Power For Wire - <	50 Watts
Approximate Total Power (Neglecting A.C. Power Factor)	3620 Watts
Estimated Pumping Speed - > 1/2 cc S.T.P. Gas per second	
Base Pressure - < 10^{-8} mm	

FIGURE 3

26
~~SECRET~~

150 027

~~SECRET~~

UCRL 4795

THEORETICAL

(Marvin Mittleman)

Various models for a steady state hydromagnetic shock are being investigated. For Rosenbluth's model (adiabatic electrons, cold ions and no collisions) it is found that there can be no shock (only a pulse) if the pulse speed is less than twice Alfven speed. Otherwise the ions will loop in their paths and the model breaks down. A model with electrons and ions of equal mass, both initially cold, gives qualitatively the same results. It is thought that the difficulty with both these models is their inability to account for looping in the particle paths.

In order to remedy this the Boltzmann equation for equal mass electrons and ions, with no collisions is being considered. A method for solving it in the limit of strong shocks has been found, but the interpretation of the results has been difficult. Numerical means for solving it for intermediate shock strengths are being considered.

Non-Adiabatic Effects (Henrich, Northrop, Riddell, Garren)

The investigation of non-adiabatic effects for single particle motion has continued. There was some attempt to find out whether the total change in J , the action integral which is equivalent to W_1/B , on multiple reflection was limited or not. No satisfactory method of determining this was found.

Additional calculations have been made to determine the change in J as a function of the parameters $(v, p_\theta, \delta, \lambda)$ where v, p_θ are the dimensionless velocity and angular momentum (the two constants of the motion), δ is the polar angle with respect to the axis of symmetry in a plane midway between the mirrors, and λ the azimuthal angle. The fields, as before, were about those expected for Felix. Keeping (v, p_θ, δ) fixed the value of $\Delta J/J_0$ was plotted as a function of λ to find the maximum. If this maximum change in J/J_0 , i.e., $(\Delta J/J_0)_{\max}$ was calculated for an ion starting in the median plane of the machine and returning to the median plane, $(\Delta J/J_0)_{\max}$ was approximately proportional to v . The change in J between successive reflections was also calculated. In this case by plotting $\Delta J/J_0$ against $1/v$ on a semilog scale; one finds

$$\left(\frac{\Delta J}{J_0}\right)_{\max} \approx a e^{-b/v}$$

for the calculated cases. In this case the shifts in J in the two ends of the field apparently tend to cancel out.

Calculations are also planned for a case where the two ends of the field are not symmetrical.

Analytic work has also been carried through to try to represent these shifts in J . The analysis so far seems to give quantities of the right order of magnitude in some cases. But possibly higher order expressions which are messy to derive are needed to obtain good agreement.

~~SECRET~~

~~SECRET~~

UCRL 4795

Mirror Machine (A. Kaufman)

For an isolated plasma, confined between mirrors, and subject to mirror losses by velocity-space diffusion, a qualitative study has been made of the flute instability. One finds an exponentiation time of the same order as predicted by the Frieman hydromagnetic energy principle for wave lengths of the order of the ion Larmor radius. Presumably an external plasma can damp this instability, by space charge neutralization.

Hydromagnetic Theory:

In collaboration with K. M. Watson, a method is being developed for treating plasma problems in which collision effects are negligible, and the deviation from equilibrium is small. This theory is capable of describing oscillations and instabilities for which longitudinal electric fields and pressure gradients may exist.

Diffusion Theory:

A theory is being developed for processes in which particle collisions are dominant, to describe plasma diffusion in a magnetic field, due to pressure and temperature gradients. It is planned to use numerical methods for solving the resulting equations.

Helmholtz Instabilities:

Using the conventional hydromagnetic equations, the work of T. Northrop has been extended to the case of a surface of discontinuity in a plasma, with arbitrary discontinuities in density, field, and tangential velocities. One finds complete analogy to the hydrodynamic solution, with effective densities and pressures as discussed by Northrop (UCRL-4663).

End-Loss Problem (J. Roberts)

The Alice Univac calculation with the semi-empirical fudge factors mentioned in the last progress report was carried out for a normal mode angular distribution. The results were in qualitative agreement with earlier computations, i.e., scooter and unfudged Alice, but indicated a lower end rate than either of these others.

One of the reasons for introducing the fudge factors was to facilitate the calculation of the decay of a peaked angular distribution, and a peaked distribution was then calculated. Its most interesting feature was that the peaked distribution rapidly rearranged itself toward the normal mode distribution, the rearrangement being largely accomplished before any appreciable end loss had occurred.

The 704 calculation is at present in the coding stage. It will have the advantage of being performed without resort to some questionable approximations which were necessary on the Univac. The code is also being arranged to give supplementary information. Unfortunately, it appears that computing the reaction rate will be too time consuming to include as an integral part of the problem but rather will have to be done separately later and at a relatively few selected points. However, the following information will be provided as a more or less integral part of the calculation: charge exchange reaction rate, particle density and particle density between certain speeds and directions, mean energy, speed, and direction of the particles, their mean speed along the magnetic field, and a function indicating the extent to which the distribution is deviating from a normal mode distribution.

~~SECRET~~

150 029