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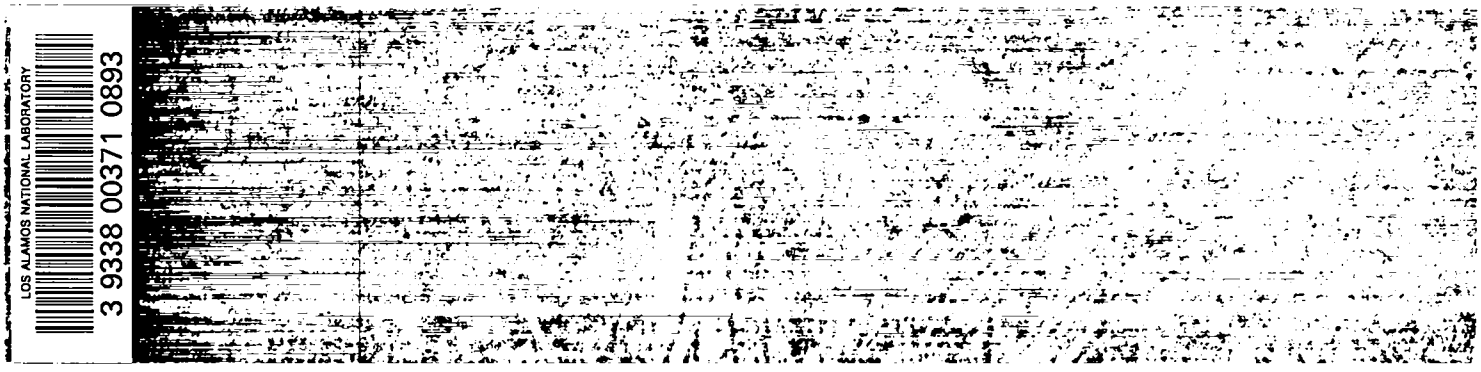
LOS ALAMOS SCIENTIFIC LABORATORY

OF THE UNIVERSITY OF CALIFORNIA o LOS ALAMOS NEW MEXICO

QUARTERLY STATUS REPORT OF THE LASL
CONTROLLED THERMONUCLEAR RESEARCH PROGRAM
FOR PERIOD ENDING NOVEMBER 20, 1961



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LOS ALAMOS SCIENTIFIC LABORATORY
OF THE UNIVERSITY OF CALIFORNIA LOS ALAMOS NEW MEXICO

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Prepared from material submitted by members of P Division

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LASL SHERWOOD PROGRAM QUARTERLY REPORT

This report contains a summary of the work done in connection with the LASL Sherwood Program during the three months ending November 20, 1961. Further details of the experiments and results will be published either in the open literature or as unclassified LASL reports.

BAKEABLE PICKET FENCE EXPERIMENT

Measurements of the coaxial gun output, the injection process, and characteristics of the trapped plasma have continued in the Mark II (Bakeable Picket Fence) experiment. The gun is found to eject initially a group of fast electrons (energy > 13 kev deduced from x-rays) followed by a plasma blob with a deuteron mean translational energy of ~ 13 kev and an average density of ~ 2×10^{13} deuterons/cm^3 at the entrance cusp of the picket fence.

In the ring cusp region a rapid magnetic field perturbation ($\beta \approx 1$) is observed for the first 1-4 μsec after the initiation of the gun, followed by smooth decay from high β with an initial decay time of 10-40 μsec, breaking into a second longer decay time. The dependence of the second decay time of neutron production is a steep function of the magnetic field strength and at 3.5 kgauss is ~ 100 μsec.

The spatial source of neutrons ($\leq 5 \times 10^6$ per discharge) is still unresolved. Soft x-rays have also been detected, and an absorption curve is in agreement with an electron temperature of ~ 1.4 kev. The x-ray intensity follows within experimental error the same characteristic decay rates as the neutrons.

CAULKED PICKET FENCE EXPERIMENT

The purity of the plasma ejected by the coaxial gun in the Caulked Picket Fence experiment has been measured with a time-of-flight mass spectrometer. The results show that the deuterium plasma is less than 10% contaminated by impurities of atomic mass > 8. Experiments to study the trapping of high-energy ions similar to that in Mark II Bakeable Picket Fence experiments have been started with the magnetic field coils connected for simple picket fence geometry. The gun has been adjusted to produce high-energy deuterons and enhancement of the neutron yield by escaping deuterons is accomplished through use of D_2O-ice targets.

RESONANT HELIX EXPERIMENT

In the Resonant Helix experiment the following program is being investigated: (a) the determination of confinement times of injected electrons as a function of mirror ratio, and (b) the characteristics of a resonant rotating magnetic cusp perturbing field and of a spatially resonant field, as examined by Sinelnikov.

The action of a helical perturbing field (resonant helix) on a plasma jet produced by a coaxial gun is being studied. The diamagnetic signal produced by the passage of plasma along a longitudinal magnetic field was measured at the entrance and exit of the resonant helix. The helix increased the diamagnetic signal, indicating that longitudinal energy had been transferred into the transverse direction.

A magnetic mirror field, mirror ratio ~ 3, placed beyond the resonant helix effectively prevents transmission of the diamagnetic signal down the tube when the perturbing field is turned on. This result is surprising since it had been argued that the perturbing field could not penetrate the plasma jet due to its relatively high conductivity. In this particular experiment the diameter of the glass vacuum chamber is too small to permit effective diagnosis of the behavior of the helix on the plasma jet since the expanding diameter of the jet causes some plasma to interact with the wall.

FAST LINEAR PINCH

A fast linear pinch experiment has been initiated. In an attempt to reduce discharge hang-up at the wall at high voltage gradients ($\leq$ 6 kv/cm), a plasma column is injected axially from a coaxial gun through hollow electrodes. The glass discharge tube wall is placed at some distance away from this plasma so that the wall is insulated from the plasma by the initial high vacuum. To date no effect of the linear pinch on the plasma has been observed.

ELECTRODELESS PLASMA GUN

Experimental work has been started on the electrodeless plasma gun consisting of one half of the mirror coil geometry of the orthogonal pinch experiment. Measurements have been made on the plasma velocity ($\sim$ 5-10 x 10^7 cm/sec near the coil exit), and momentum ($\sim$ 150 dyne-sec at $\sim$ 30 cm from the driving coil) at various axial distances from the coil. The ejected plasma is found to contain trapped magnetic fields with a diffuse current boundary separating two magnetic field regions of opposite sign.

INCOHERENT SCATTERING OF MICROWAVES

Measurements on the microwaves scattered incoherently, i.e., with a frequency shift, by the large open plasma chamber have been concluded, and are to be continued at higher frequencies inside of a long waveguide chamber. Observations to date have indicated that external radiofrequency fields can induce density fluctuations when they exist in the presence of density gradients. Polarization properties, angular intensity distribution, and frequency spectrum of the resulting scattered radiation have been studied.

COLLISIONAL RELAXATION

The production of second peaks in the velocity distribution of plasma particles has been studied under various actual plasma conditions.

Results are now available which show that collisional relaxation between a small group of fast test particles and a large group of slow field particles can under certain conditions give rise to second peaks, and electrostatic instabilities.

NEGATIVE CYCLOTRON ABSORPTION

Calculations of cyclotron absorption coefficients are under way. For certain peaked non-Maxwellian velocity distributions the results obtained indicate negative absorption. The effect on these coefficients of varying certain plasma parameters is being studied.

INJECTED SCYLLA III, NEUTRON DOPPLER BROADENING MEASUREMENTS

A preliminary attempt has been made to determine the final deuteron ion temperature in the case of a parallel magnetic guide field with Scylla operating on the fast component of the injected plasma (cf. LAMS-2529, p. 25). The object of the measurement was to determine if the compressed ion energy was in the predicted region of 30 kev.

The energy spectra of the neutrons emitted from a plasma at a temperature of 30 kev will have a width of approximately 260 kev, corresponding to the thermal broadening. Although such a width is well within the resolution of available techniques, it is very difficult to obtain a neutron energy spectrum in good collimated geometry. A preliminary indication of the spectrum, and therefore the ion temperature, may perhaps be obtained in an uncollimated geometry by recording only the proton recoil tracks which have the longest ranges in the nuclear emulsion. This technique requires a large number of tracks, since the quantity which determines the neutron energy distribution is the derivative of the proton energy spectrum at its upper end. In the case of Scylla III good statistics are difficult to obtain, and so final data must await completion of Scylla IV.

Some results of the experiment are shown in the histograms of Fig. 1, giving the energy distributions of long-range proton recoils. The curves drawn through the upper end of the histograms correspond to integrated Maxwellian distributions. In the case of both the radial and axial data for injected Scylla the distributions have large slopes at their upper ends consistent approximately with the expected 30 kev temperature.

APPLICATION OF THE HAIN-ROBERTS HYDROMAGNETIC CODE TO SCYLLA

In collaboration with K. and G. Hain from the Institut für Plasmaphysik, Garching, Germany, the Hain-Roberts hydromagnetic code has been reassembled for the Los Alamos IBM-7090 computer and run with parameters applicable to the Scylla I, θ-pinch. The newly assembled code has now been successfully run for a complete half-cycle (2.5 μsec) of the Scylla I discharge current, assuming an initial fully ionized plasma with $T_e = T_i = 2$ ev, $n_o = 5 \times 10^{15}$ cm^{-3}, and initial bias magnetic fields of -4, 0, or +4 kgauss. With no on-line printing, a half-cycle requires about 1-1/2 hr of computer time with a time step of $\sim 2 \times 10^{-4}$ μsec. Results will be compared with the large body of Scylla I measurements and also with those of the larger Scylla III machine. Some predictions concerning Scylla IV plasmas may also be attempted.

ZEEMAN EXPERIMENT

The apparatus for the experiment (cf. LAMS-2444, p. 34) has been constructed and the intricate alignments of the optical elements have been made. In addition to usual spectrograph alignments, it is necessary to place the Babinet-Soleil compensator and Wollaston prism with their optic axis in precise angular orientation with respect to the slits and grating rulings. Bench tests indicate that the apparatus operates as planned, although the fiber element is imperfect, having a step in the vertical dividing line of fibers. A central column of fibers has been masked off

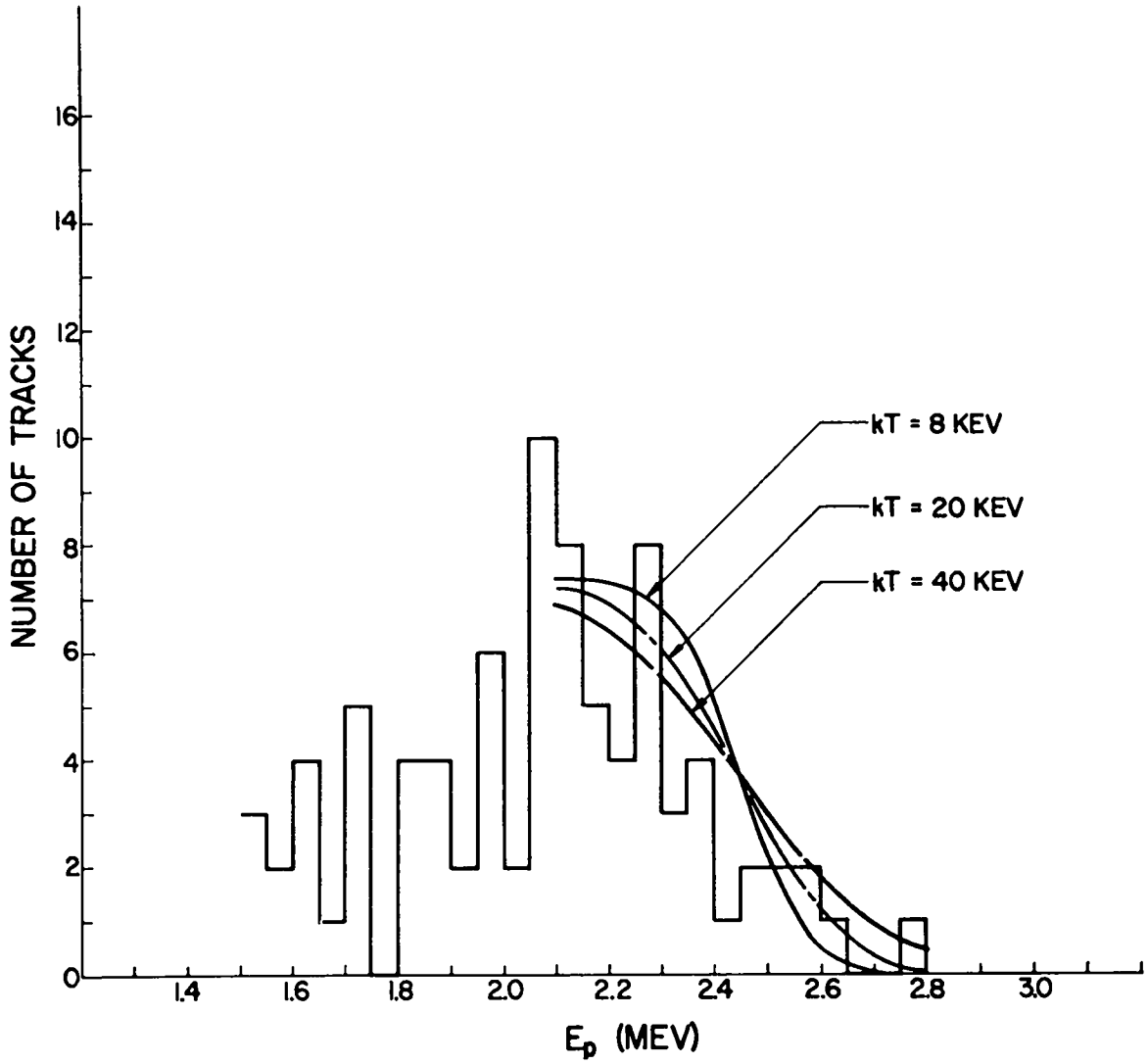

Fig. 1. Neutron-proton recoil energy distributions.

to eliminate the step. Eventual replacement of this element is under consideration, probably by a pyramidal beam splitting mirror. Such action will be postponed, however, until after some measurements are made on Scylla.

A NEW TYPE OF FRACTIONAL TURN MAGNETIC COMPRESSION COIL

A new principle has been developed for building fast magnetic coils which have no feed point asymmetry and are capable of voltage multiplication from the energizing capacitor bank to the plasma. A quarter turn of the coil is shown in Fig. 2. In the absence of common collector plate connections, four separate banks would be used in series. A coil of this type has been built as a model and found to exhibit the expected inductance and voltage multiplication.

Since the inductance of a fractional turn coil is much smaller than that of a conventional coil of one turn - a quarter turn coil for instance has only 1/16th that of a one turn coil - the inductance of the bank that feeds it must be very small indeed. It is easier, however, to achieve low inductance at reduced voltage, and this appears to more than compensate for the extra difficulty introduced.

E X B ACCELERATOR

Experiments with Applied Electric Fields

It has been reported (LAMS-2619, p. 27) that the plasma from the gun which is normally stopped by transverse magnetic fields ≥ 5 kgauss was apparently accelerated upon application of an electric field between plate electrodes downstream in the magnetic field. It now appears that the plasma which emerges from these electrodes is not injected plasma from the gun but rather (primarily) new plasma from a discharge between the plates which is "seeded" by some of the injected plasma. This is particularly indicated by the fact that the current to the E-field plates can be delayed by as much as 30 μsec after the arrival of plasma from the injector gun. The characteristics of this plasma discharge are very similar to those observed in the Ixion rotating plasma experiment.

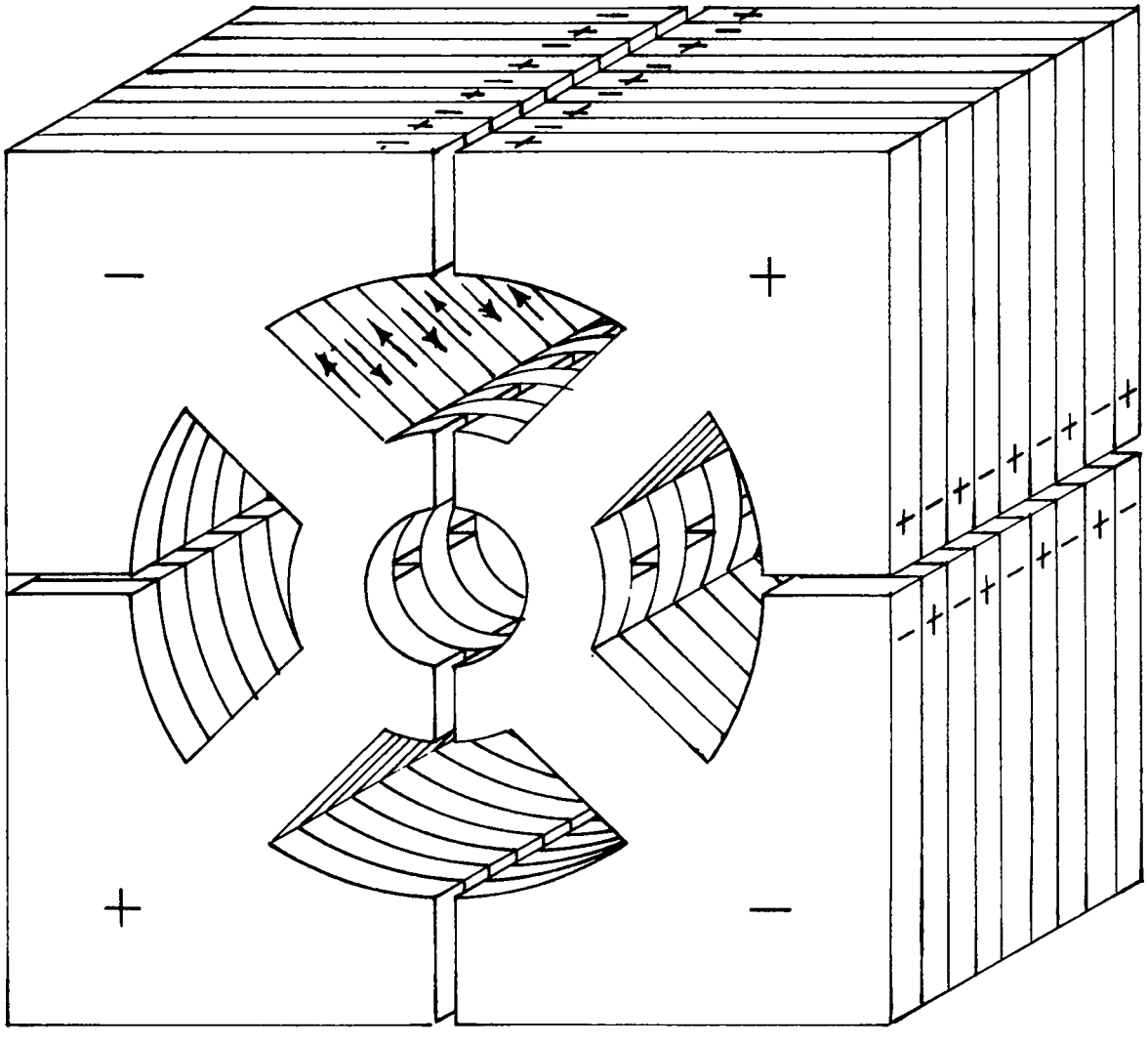

Fig. 2. Quarter turn magnetic compression coil.

Experiments Without Applied Electric Fields

In experiments on the polarized plasma beam as it proceeds across the magnetic field, the expected classical behavior of the flowing plasma has been studied at "obstacles" in the form of shorted regions of electric field. Conductors perpendicular to the magnetic field, well outside the path of the plasma, project regions of zero electric field along the magnetic lines into the path of the plasma. Thus without encountering a material obstacle, the plasma stops or flows around these regions of zero electric field. The plasma used in these observations is that which emerges from between the plates in the experiments described above.

Since the plasma is well penetrated by the transverse B-field, the plasma should be polarized in the region beyond the electrodes, thus establishing the proper electric field to continue the E X B motion across the magnetic field. To confirm this expectation, a thin curved stainless steel liner was placed adjacent to the interior wall covering half of the wall circumference. This permits the polarization charge to be effectively discharged since the electrons can travel readily along the magnetic field lines. The thin stainless steel sheet was sufficiently resistive to allow the magnetic field to penetrate readily. With the electric field annihilated, the plasma E X B drift motion should no longer continue, and this was indeed observed. The time integrated photograph in Fig. 3 shows the abrupt braking of the plasma when it reaches the region of the "shorted B lines," the lines being out of the paper. Part of the plasma actually reverses its direction of motion.

In another experiment a narrow strip was used, again adjacent to the interior surface of the wall normal to B. The narrow side was oriented normal to the incident beam so that only a portion of the drift region had B-field lines passing through the short. As can be seen in Fig. 4, no plasma passes through the shorted region. Kerr-cell photos indicate that there is a stagnation of plasma ahead of the shorted region, and that a portion of the plasma divides and passes around the forbidden

Fig. 3. Plasma moving transverse to a magnetic field being stopped by a region of zero electric field.

Fig. 4. Plasma flowing around a region of zero electric field.

region. Magnetic probe measurements confirm that the photographically dark regions observed in these experiments do not contain plasma.

CAPACITOR BANK SYSTEMS

Zeus

The coils designed to duplicate cable inductance in the Zeus bank were tested in a shelf at the maximum voltage and current expected in Scylla IV. The system was fired until a capacitor failed. The isolating coil exploded because the particular design was somewhat minimal. A test jig was built and a number of designs were evaluated until a satisfactory coil was developed. It turned out to be 1/8-in. copper rod potted with fiber glass reinforcement. The design is fairly expensive, so it was decided to use all full length cables in the installation.

The trays, which hold the cables in Zeus, have arrived and some have been loaded with cables and installed. The coax headers have arrived and the first unit is being evaluated. The 3-megajoules of Zeus, which will be used with Scylla IV, are now being rebuilt with the cable transmission system.

Scylla IV

A few models of the 50-kv spark gap, which operates under oil, have been built and evaluation begun. Some problems in triggering the gap have developed. The solution appears to be in a redesign of the trigger spark plug. Five units have been modified and are being evaluated. The racks for the 50-kv capacitors have been ordered. The platform for the 50-kv bank has arrived and is being installed.

A new type 0.8-μf, 120 kv, low-inductance capacitor has arrived but has not been voltage tested yet. Its measured inductance is less than 32 nanohenries. A spark gap for this capacitor is being designed, which will use the same electrodes as the 50-kv gaps.

The installation of the utility power and the 50-kv main charging power supply is under way.

PUBLICATIONS

"Maxwell Averages for DT and DD Below 1 Kilovolt," LAMS-2603.

"Proposal for a 3.5-Megajoule Magnetic Compression Experiment --Scylla IV," LAMS-2609.

"Stability of a High-Speed Plasma Stream," LAMS-2633.

"Thermonuclear Reaction Rates," Nuclear Fusion 1, 201 (1961).

"Injection and Trapping of a $\beta = 1$ Plasma into a Cusped Magnetic Field," Phys. of Fluids 4, 905 (1961).

"Soft X-Ray Spectroscopy of a Hot Plasma," IRE Transactions on Nuclear Science, Vol. NS-8, No. 4, October 1961 (Proceedings of the Joint Nuclear Instrumentation Symposium.)