CERN/FSG/11
17 August, 1959.

CERN STUDY GROUP ON FUSION

Fourth Meeting

Harwell - 18, 19 and 20 June, 1959

MINUTES

Chairman:	J.B. Adams		
Attendance:	Ch. Lafleur	Free University of Brussels	Belgium
	C.F. Wandel	Risö Research Establishment	Denmark
	P.M.C. Ginot	C.E.A., Saclay	France
	C.H. Mercier	" "	"
	F. Prévôt	" "	"
	J. Taillet	" "	"
	M.G. Trocheris	" "	"
	G. Vendryes	" "	"
	S.D. Winter	" "	"
	P. Grivet	University of Paris	"
	L. Biermann	M.P.I., Munich	German Fed. Rep.
	G.O.J. von Gierke	" "	" " "
	K. Hain	" "	" " "
	H. Fay	Technical University, Aachen	" " "
	H.L. Jordan	" " "	" " "
	J.E. Allen	C.N.R.N., Lab. Gas Ionizzati, Rome	Italy
	B. Brunelli	" " " " "	"
	S. Segre	" " " " "	"
	C.M. Braams	F.O.M., Jutphaas	Netherlands
	H.C. Brinkman	" Amsterdam	"
	D. Th. J. ter Horst	" "	"
	H. Brinkman	Natuurk. Lab., Groningen	"
	J. Kistemaker	Lab. for mass spectrography, Amsterdam	"
	K. Johnsen	Technical University, Trondheim	Norway

PS/793

Attendance (cont'd):

N.B. Agdur	Royal Inst. of Techn.,Stockholm	Sweden
A. Dattner	" " " " "	"
S.U.G. Svennerstedt	Uppsala University, Uppsala	"
H.E. Knoepfel	E.T.H., Zürich	Switzerland
R.J. Bickerton	A.E.R.E., Harwell	United Kingdom
T.F. Johns	" "	" "
R.S. Pease	" "	" "
W.B. Thompson	" "	" "
P.M.S. Blackett	Imperial College, London	" "
R. Latham	" " "	" "
S.C. Curran	A.W.R.E., Aldermaston	" "
G.B.F. Niblett	" "	" "
D.R. Chick	A.E.I. "	" "
A.A. Ware	" "	" "
D. Palumbo	EURATOM	
P.J. Frank	O.E.E.C.	
J.B. Adams	CERN	
J.G. Linhart	"	
E. Regenstreif	"	

- - - - - - - - - -

The Chairman reported on the discussions of the last CERN Council Meeting pertaining to the future of the Study Group on Fusion. Most of the Council representatives felt that since fusion research does not form part of the programme of CERN, it should not continue to sponsor the Study Group beyond the end of the year. The Group should therefore be encouraged to set up its own society.

After discussion it was agreed that the delegates should take up the matter with their authorities or governments and report to the Chairman before the next Meeting.

Fifth Meeting of the Study Group

The next Meeting will take place on 26 and 27 November, 1959 at Munich.

Visits to Laboratories

Special sessions were arranged to take the visitors round the Laboratories at AERE Harwell and AEI Aldermaston; opportunity was provided for them to see in detail the work on fusion going on there.

TECHNICAL SESSIONS

Hubert reported on a single coil mirror experiment. By means of a condenser bank of 100 μF, charged at 20 kV (20 kJ stored energy), a discharge was struck through a deuterium gas enclosed in a spherical pyrex vessel of 30 cm diameter. A loop of brass of 140 mμH inductance, suitably wound around the pyrex vessel, provided a mean mirror ratio of $B_e/B_0 = 2{\cdot}5$. The discharge period was 30 μs and the maximum field at the centre of the sphere was 8'000 Gauss in the absence of the discharge. Preionization was obtained by means of an RF coil placed in a plane parallel to the mirror axis and fed by a 20 Mc/s, 400 W generator. Initial pressure of the deuterium gas was of the order of 10^{-2} mm Hg.

Various diagnostic techniques were used, such as magnetic probes, spectroscopic measurements, microwave noise (38'000 ± 7 Mc/s), fast camera records (2/10 μs exposure time, 1 image/μs) and X-ray studies.

Most puzzling was the evolution in time of the observed magnetic field configuration (Fig. 1). Experiments are under way to interpret this behaviour.

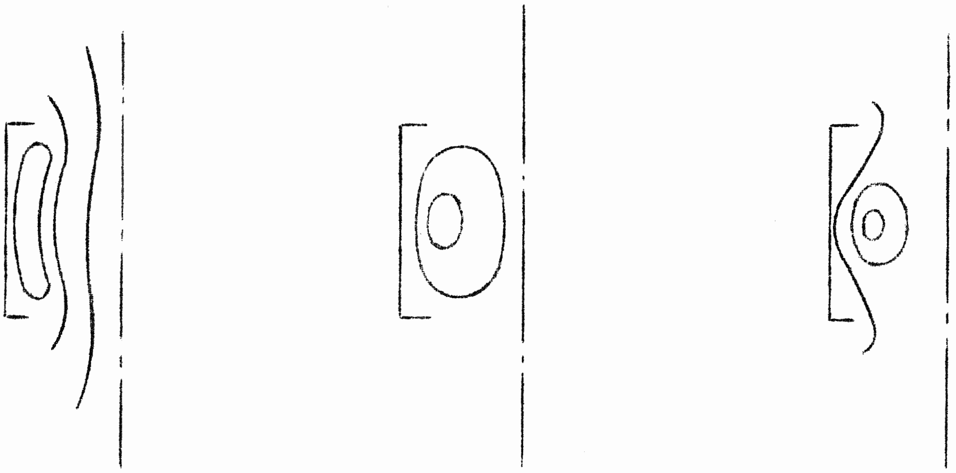

Fig. 1

Ginot reported on experiments carried out with TA 2000. This is an annular discharge device (large diameter 2 m, small diameter 30 cm, wall thickness 1 cm) described in the Geneva Conference papers. A stainless steel liner has now been provided on the inside of the torus to improve the distribution of the induced electric field. The following experiments have been performed:

1. The vacuum has been pushed down to 3.10^{-8} mm Hg in the region far away from the pumping manifolds.

2. The breakdown range has been investigated and a set of curves has been drawn giving the breakdown field (V/cm) as a function of the pressure and the magnetic field. The curves show curious characteristics (independence of the breakdown on voltage and pressure within a certain range, existence of an upper limit for the voltage, etc.).

It has been possible to obtain breakdown down to 2.10^{-4} mm Hg.

3. X-rays have been investigated. Observations were made across a beryllium window 0·1 mm thick, by means of a scintillator (plastic or INa) followed by a photomultiplier. A tungsten target could be moved along a diameter of the discharge.

X-rays were produced essentially during the predischarge and also under certain conditions during the initiation of the main discharge.

Absorption measurements indicated energies of the order of 10 keV. Photographic records show that the X-rays are produced by impact on the walls of electrons accelerated perpendicularly to the plane of the torus. By putting an extra magnetic field on one side of the discharge the X-rays completely disappeared.

4. Spectroscopic studies (filling pressure 5.10^{-4} mm Hg) gave the following results:

a) The overall spectrum showed no observable traces of wall material in the discharge. In addition to the Balmer lines, atoms and ions of C^{I} to C^{IV} and O^{I}, O^{II} were identified. A measurable broadening of C^{III} 2296·9, if attributed to a Doppler effect, would lead to an ion temperature of $4{\cdot}5.10^{5}$ °K.

b) Measurement of relative intensities of various lines show that the hydrogen is completely ionized at maximum current (half-period 200 μs), that the C^{II} ion disappears right at the beginning of the discharge (25 μs) and that ionization of C^{III} starts at 50 μs.

c) Interpretation of the results based on assumptions made in solar corona work would lead to an electron temperature of $8-9.10^4$ °K at maximum current.

Prévôt reported on the DC mirror project.

In electric or magnetic fields possessing axial symmetry, charged particles injected from the outside can be made to go through the axis if the magnetic flux satisfies a certain condition and if the initial energy of the particles exceeds a lower limit E_o . The particles can then be trapped by arc dissociation on the axis if their energy is smaller than a given value, which under certain particular conditions is $4\,E_o$.

Several methods can be used for achieving multiple traversals of the axis resulting in a considerable improvement of the capture efficiency. These properties can be put to good advantage in creating and confining a hot plasma by a magnetic field. A few problems associated with the practical application of this scheme, such as ion sources, space charge, vacuum and magnetic field have been investigated. No major difficulties have been found so far.

By writing down the equations of motion it can be shown that the flux condition mentioned above is equivalent to Busch's theorem

$$\frac{e}{2\pi m}\,(\varphi_1 - \varphi_2) = r_1^2\,\dot{\theta}_1 - r_2^2\,\dot{\theta}_2 \qquad (1)$$

where symbols are self-explanatory.

A particle accelerated in an electric field has its orbit in a meridian plane. In the absence of magnetic field $\theta_1 = 0$, and to go through the axis $(r_2 = 0)$ the flux φ_1 at the place where injection occurs must be zero. This means that the magnetic lines of force close on themselves inside the accelerating region. This result does not depend on the value of the electric field accompanying the magnetic field or the particle velocity. Consequently, if the particles go through the axis, this status can be maintained in the presence of space charge and within a certain range of particle energy. However, the energy of the injected particle must be sufficiently high so that the particle can penetrate into the magnetic field and overcome a possible repulsive electric potential. This condition is very complicated in general, but simplifies in the case of plane motion perpendicular to the axis (magnetic mirror machine).

In practice the trajectories can be simply visualized in the case of plane motion in a uniform magnetic field (Fig.2).

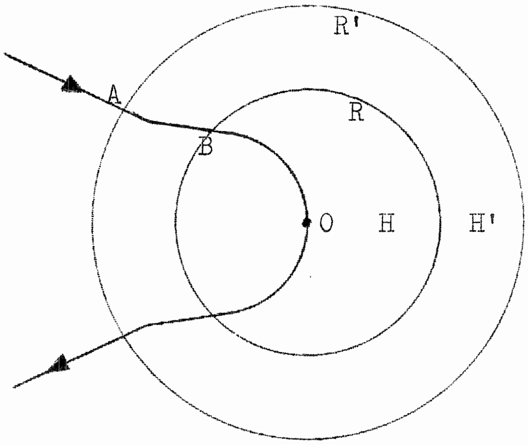

Fig. 2

H is a uniform field inside a circle of radius R . H' is a uniform field of opposite direction localized in the annulus $R' - R$. The particle is injected normally to the circle R' . It describes an arc of a circle inside the annulus and an arc of opposite curvature inside the circle R . The condition that the particle should pass through the axis leads in a simple way to eq. (1). If the motion is free, the particle will emerge from the magnetic field in a symmetrical trajectory. However, if a Luce arc is maintained on the axis, molecular ions injected will undergo dissociation and the radius of gyration will be halved.

To obtain multiple traversals several methods can be applied, for instance oblique injection (Fig.3) or letting the particles be decelerated

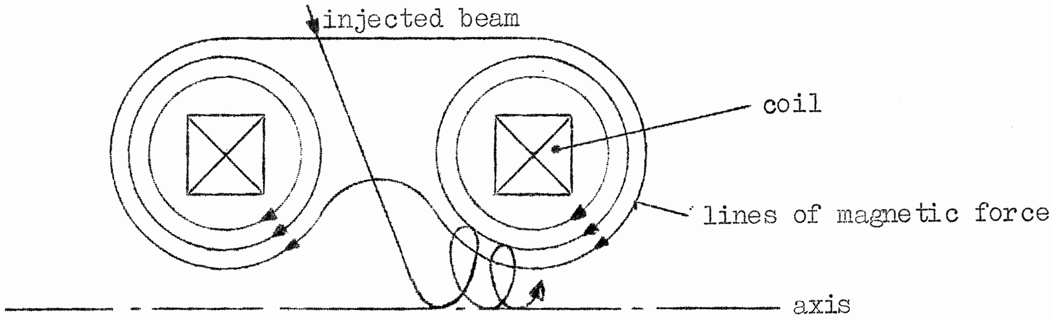

Fig. 3

in the electric field which had accelerated them from the ion source (Fig.4). In the first case the total capture efficiency might be as high as 90 o/o

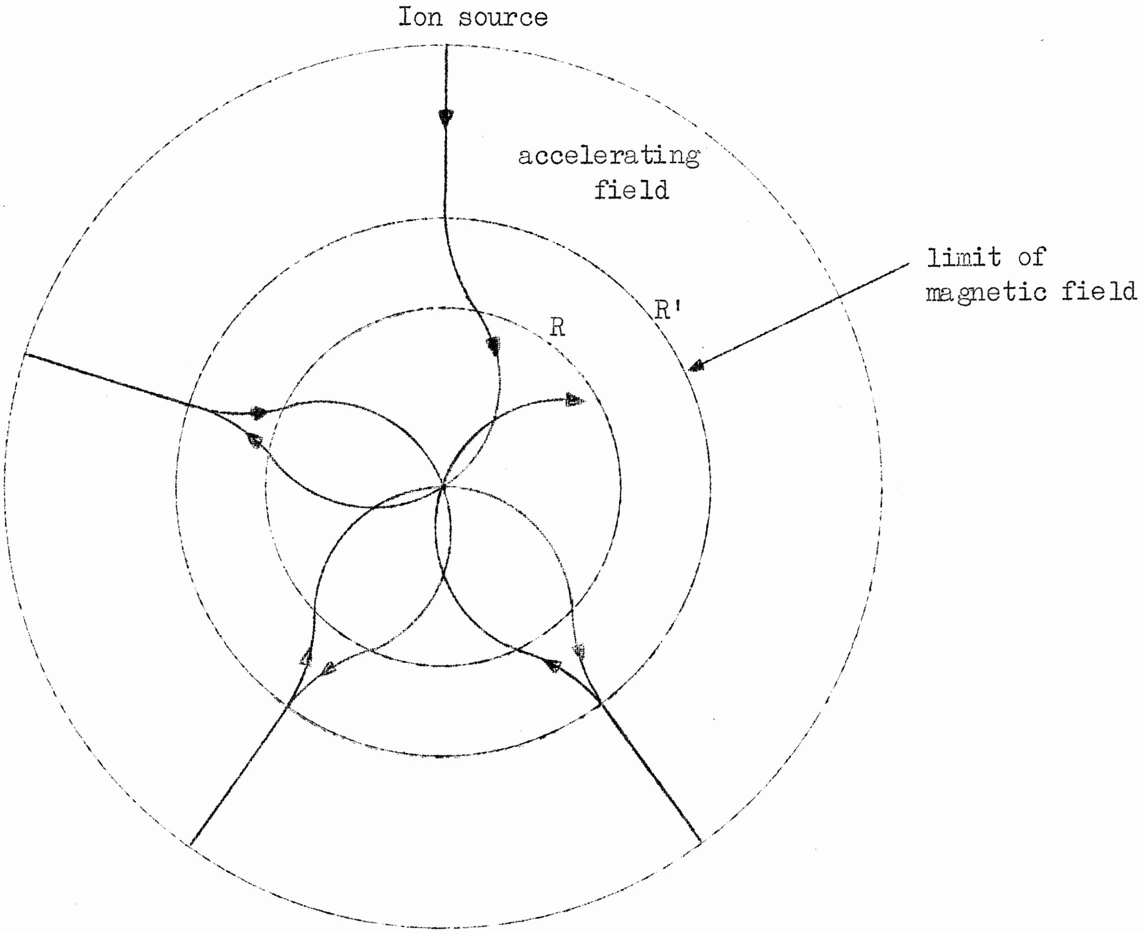

Fig. 4

The construction of an annular ion source giving 100-300 mA distributed on a circumference of 30-40 cm radius does not involve any special difficulty.

Calculations have shown that space charge due to transit ions does not prevent injection in the range actually considered, i.e. V = 100-200 kV, I up to a few amps. However, trapped ions do prevent it if the density exceeds $10^9/cm^3$; compensation can be obtained by a suitable number of electrons in the plasma.

The required vacuum is 10^{-7}- 10^{-8} mm Hg, and the gas influx from the ion source could be a serious limitation here.

For an injection energy of 200 keV, the magnetic bottle would have 15 kGauss in its centre and 30 kGauss at the mirror ends.

By choosing for R the minimum value compatible with the magnetic field and injection energy, a large range in β can be used for exploration.

Design studies are being worked on.

Taillet mentioned the programme of his group at Saclay:

1. Plasma betatron in connection with work carried out in CERN.
2. Ionization and dissociation cross-section measurements.
3. Small size moderate temperature plasma experiments.

The following table sketches the experimental effort:

Type of plasma	Effects to be studied or parameters to be measured	Diagnostic methods used
RF Plasma	$\omega_p = \omega_{ex}$	Langmuir probes Frequency shift measurements
PIG	Ionization potential distribution Diffusion	8 mm wavelength Langmuir probes
ARC	Ionization in arcs Diffusion Pumping	8 mm wavelength 4 mm wavelength Interferometer Probes

Biermann reported on the general organization of work in plasma physics in Germany.

Jordan reported on work carried out by the Aachen group which will be moving to Julich early next year. They have recovered from the fire and the workshop is now in operating conditions.

1. One experiment is left over from the linear stabilized pinch. This involves low voltage gradients and currents up to 100 kA.

2. Schlüter's group is making complete plots of B_r , B_Θ , B_z as a function of radius and time in a linear discharge possessing rotational symmetry. These plots will be used to calculate the conductivity, the electric field and the velocity as a function of radius and time. The energy balance equations (involving heat and kinetic energy) can then be written out numerically.

3. Some larger experiments are being put up.

An experiment intended to study fast magnetic compression (a fast rising magnetic field compresses plasma in a tube) has been running for some months. The main interest here is centred around the early stages of the development of the discharge. Only axially homogeneous fields have been used. Stored energy was of the order of 1 kJ, peak field about 30 kG, time to first compression 0·4 μs.

This experiment is now continued with two identical condenser banks of 5 kJ storing capacity each.

Another experiment has been set up to study the initial phases of preheating.

A third experiment is intended to extend the data up to 200 kG.

These experiments involve small volumes (10 cm length, 2 to 4 cm transverse dimension). Larger volumes will be used in connection with a new condenser bank of 40 kJ storing capacity. This bank is in the stage of construction.

4. Development of Magnetic Probes.

The aim here is to develop a reliable probe, allowing to determine the current distribution in a quasi-stationary, high frequency plasma.

The high frequency field is produced by feeding a copper tubing coil (90 mm diameter, 10 turns of copper tubing) by means of a self-excited 15 Mc/s RF generator. The probe can be brought into the field of this coil and displaced radially with an accuracy of 0·01 mm. Plasma or electrolytes can thus be explored.

The probe is a two-layer cylindrical coil of 0·5 mm core diameter and 1·8 mm length. Each layer has 20 turns of copper wire of 0·05 mm diameter.

The signal is measured with an oscillograph in connection with a differential preamplifier.

The coil is tapped at its centre and the centre can therefore be connected to earth. When the resonant frequency of the measuring coil exceeds the RF frequency of the field to be measured, the centre earthing achieves short-circuiting of perturbing voltages capacitively coupled to the coil. The leads to the coil are screened by metal tube of 0·9 mm diameter. The residual perturbing voltage is further reduced by the use of the differential amplifier.

The measurements show that the behaviour of the probe is linear up to 30 Mc/s. The resonant frequency of the coil is 47·5 Mc/s.

Tests have been made to determine experimentally the perturbation of the field by the presence of the probe. Cylinders of 60 mm diameter of various materials (aluminium, graphite, etc.) and various radial dimensions were brought into the RF field and the radial dependence of the B_z field was measured with the probe.

As expected, the measurements show that the perturbation of the field configuration decreases when the diameter and the conductivity decrease. In trying to determine the limits of applicability of a probe, the penetration depth of the field is a better measure than the conductivity.

<u>Schlüter</u> gave a summary of the theoretical work being carried out at the Max Planck Institute, Munich. This work falls into three categories: theory related to specific experiments, general applied theory, and pure theory.

1. Theoretical Work Related to Specific Experiments

a) Initiation of an endless discharge. This work is meant to apply to early stages (ionization, breakdown) of a toroidal discharge.

b) Investigation of possible conditions under which one could always obtain stability in a straight pinch discharge, for instance by programming B_z and having that field diffuse into the plasma.

No configuration of definite stability could be established, but it was found that stability can be improved by reversing B_z .

Two ways of attack were followed:

i) by judging stability according to the Suydam criterion,

ii) by using the magneto-hydrodynamic approximation.

c) An attempt is being made to solve numerically a set of equations representing as realistically as possible a pinched discharge. The computation includes finite resistivity and heat conductivity.

d) A possible way of designing a fast stellarator is being thought of. The first problem here is to devise a set of coils so that the plasma contracts towards the axis and is stable. One might hope for stability if some lines of force are frozen into the plasma.

e) The behaviour of a modulated ionic beam has been looked at. The idea is that such a beam of suitable speed and frequency should rapidly lose its energy, providing therefore a feasible means of heating plasma. Runaways and instability could possibly be avoided and non-adiabaticity would preclude the application of Liouville's theorem.

Calculations show that the energy loss is indeed appreciable if the beam is moving with Alfvén speed or if the beam is modulated with the gyro-frequency of the ions in the plasma.

2. General Applied Theory

a) Check of Suydam Criterion.

A large fraction of the activity of the theoretical group has been devoted to checking the validity of the Suydam criterion for stability in a configuration possessing axial symmetry. It has been found that the criterion is indeed necessary and sufficient for stability against localized displacements; however, some errors have crept in in Suydam's derivation.

b) RF Heating.

This problem concerns the heating of plasma by exposing it to an external radio frequency magnetic field whose frequency equals the gyro-frequency of the ions. It has been found that the resulting resonant frequency is the geometric mean between the gyrofrequency of the electrons and ions.

c) Low Frequency Heating.

Earlier attempts of low frequency heating (frequency $<$ gyrofrequency) or magnetic pumping have been followed up and calculations have been made to determine the rate of heating as a function of frequency and the fraction of the volume subjected to oscillation. The results are somewhat different from those obtained at Princeton; in particular "transit time heating" seems less effective than Princeton believe.

d) Statistical Theory of Plasma Oscillations.

This problem has been treated particularly in view of microwave investigations of a plasma. The treatment is based on usual assumptions and starts from Maxwell's equations and from the single particle Boltzmann equation. The latter is linearized and the solution proceeds according to the method of characteristics (Drummond).

e) Interaction between a Plasma and an Ion Beam.

This concerns the behaviour of a density modulated ion beam traversing a plasma perpendicularly to a homogeneous magnetic field.

f) Ionization Equilibrium.

Limiting formulae for ionization equilibrium are Saha's equation for complete thermodynamic equilibrium and Biermann-Elwert's equation for an extremely dilute plasma. Criteria and ranges of applicability are being worked out in terms of pressure and dimensions of the plasma.

3. Pure Theory

a) Magnetohydrodynamic Equilibrium.

Studies of equilibrium configurations are being continued, partly by using paper models for representing surfaces of constant pressure.

b) Confinement.

What analytical consequences on the confinement of singly flying particles can one draw knowing solely the conservation of angular momentum and energy?

c) Validity of the Hydrodynamic Approximation.

This investigation is being carried out for the case of a very dilute plasma (mean free path $\gg$ vessel dimensions). Starting point is

Boltzmann's equation for a one-component gas involving a collision term. Two cases are being considered: situation primarily governed by dissipation or by the magnetic field.

d) Microstructure of a Plasma in Thermal Equilibrium.

This is some sort of Debye-Hückel theory of electrolytes applied to a plasma.

e) Stability in the Limiting Case of Low Pressure.

Perturbation methods are applied to the general problem of stability in the case where β is small.

f) Wave Propagation and Damping by Phase Mixing.

von Gierke reported on experimental work at Munich.

1. The 1 m, 25 cm torus has arrived and installation work has started.

2. A linear discharge experiment has been set up to compare the results with those obtained with the toroidal geometry. Ultra-high vacuum will be used.

3. The possibility of using modulated ion beams (Schlüter) is being investigated.

4. Hall probes are being prepared.

5. Fünfer has also moved to the new site. His results on linear pinches have been reported and published. A new battery making a current of 800 kA possible in the discharge is being assembled.

Pease reported on work carried out at Harwell.

1. Fast Rising Mirror Device (Miller)

A small deuterium discharge apparatus somewhat similar to Scylla has been put into operation. It consists of a pyrex tube of 2·8 cm diameter and 1 mm wall thickness and a 3 cm long coil made of two single turns of copper strip, connected in parallel and fed from a small fast capacitor bank via a low transmission line. Inserted in the line are a platinum-foil current-monitoring resistance and a low inductance switch. Approximate parameters are: coil inductance 23 mμH, total inductance (coil + switch + line + capacitor) 31 mμH, storage capacity 6 μF, capacitor voltage 20 kV, peak current 250 kA, peak field on axis 6.10^4 Gauss (at centre).

The tube is pumped out to 10^{-5} mm and then filled with D_2 at about 10^{-2} mm. The pressure rises by about 10^{-3} mm after each discharge, and the system is pumped out and refilled each time. About 10^4 neutrons are observed during the second and subsequent half-cycles, but not during the first half-cycle, for D_2 pressures in the range 3.10^{-3} to 3.10^{-2} mm. No counts were observed with H_2 or He in the tube. After a few shots curious sharp bands (probably melted glass) appear on the inner wall, and also on the end face. The latter has an annular form suggestive of vortex motion.

2. Magnetic Probe Experiments in Zeta (Lees, Rusbridge)

Magnetic field configurations have been measured in Zeta using up to 16 separate search coils spaced at intervals of 3 cm along a radius. It has been found that to a first approximation the configuration does not depend explicitely on the time, but only on the instantaneous value of a quantity θ

$$\theta = \frac{2I}{a\ B_o}$$

where I is the gas current, a the discharge tube radius, and B_o the initial axial field. It is found that for θ greater than about 1·5 the radial compression of the discharge becomes approximately constant at a value near 2; this has been shown to be associated with the appearance of reversed axial field outside the discharge channel.

Fluctuations in the magnetic fields at the centre have been measured; it is found that if δB is the r.m.s. fluctuation, then

$$\frac{\delta B}{B_o} \text{ prop. } \theta^2$$

for θ^2 less than about 9; above this value a much steeper increase occurs. This point may be associated with a type of instability found at lower values of θ ; there is some evidence that the same value of θ gives a minimum in the discharge resistance and represents the point of onset of neutron production.

3. Intensity of the Spectral Lines of Hydrogen from Zeta (Whirter)

The hydrogen lines are most intense during the initial period when ionization is taking place. The absolute intensities of the first six Balmer lines have been measured during this period. The monochromator and photomultiplier were calibrated against a tungsten filament lamp of known colour temperature and luminous intensity.

The observed intensities have been satisfactorily explained in terms of the step-wise excitation of the hydrogen atoms. In these calculations the value taken for the effective electron temperature was estimated from the ionization time as measured by the duration of the H_α line.

Although no absolute measurement was made, the intensity of the Lyman α line was observed as a function of time. The intensity of this line reaches a maximum some time after the maximum of the H_α line.

4. Starting Inductance in Zeta (Butt)

The inductance of the discharge at the beginning of the pulse has been measured and the following effects were observed:

a) At normal pressures ($1/4$ μ) in deuterium, the initial inductance is anomalously high ($1\cdot5$–$2\cdot5$ μH).

b) At higher pressures (2 μ) initial inductances considerably lower than the inductance of an unpinched distributed current channel have been observed. The exact value depends on the initial axial field. This suggests that under certain conditions a skin current is set up at the beginning of the pulse. There is some confirmation of this from magnetic measurements.

The resistance of the discharge at peak current has also been measured. It has been found that this resistance goes through a minimum under certain conditions. This effect may be due, in part, to a change of inductance and is independent of pressure.

5. Rotating Magnetic Field Experiment (Blevin)

The discharge tube used is 50 cm long and has a 6 cm diameter. Two mutually perpendicular, single turn copper coils enclose the tube and two condensers (0·01 μF at 20 kV) are discharged into the coils giving a ringing frequency of 1·6 Mc/s. The two coils are fixed with a 90° phase difference and so produce a magnetic field rotating with this frequency.

If an electrodeless discharge is run in this rotating magnetic field, the drift velocity $\frac{\vec{E} \times \vec{H}}{H^2}$ of both ions and electrons will keep the plasma rotating with the same angular frequency as the magnetic field. If the gas is not completely ionized however, there will be a drag on both positive ions and electrons. At high pressures the drag on ions and electrons due to collisions inhibits any drift in the Hall direction, whereas at low pressures both ions and electrons move in the θ-direction with the Hall velocity E/H, although this is modified slightly by centrifugal effects. There exists an intermediate range of pressures (for an incompletely ionized gas) where there is only an electron current in the θ-direction. The aim of the experiment is precisely to detect these different modes of operation.

Preliminary experiments in Xenon have been carried out at higher pressures ($\sim$100 μ Hg) and as expected no evidence of θ-motion was observed. The discharge has the appearance of two intersecting ring discharges with each ring in the plane of the corresponding coil.

At lower pressures in Xenon photographs of the discharge indicate some helical motion of the discharge path, but the situation is complicated by space charge effects. The apparatus is being modified, so that pre-ionization of the gas can be incorporated. The next experiments will be carried out using hydrogen since protons are more easily accelerated to the rotating speed in the short times available.

6. ICSE (Intermediate Current Stability Experiment)

ICSE is an experiment to test the validity of the theory of the stabilized pinch. This theory is based on the hydromagnetic approximation and the key feature of ICSE is that a serious attempt will be made to ensure that this approximation is valid. This is to be done chiefly by operation at relatively high gas pressure or, in more general terms, with a large number of electrons per cm length of the discharge. In this way it is hoped to avoid co-operative phenomena resulting from runaway electrons at high drift speeds. At the same time the large line density ensures that the ratio of the ion Larmor radius to the pinch radius is small. On the debit side, the use of high density implies that to achieve substantial plasma temperatures very large discharge currents are required. A temperature of 10^6 °K was taken as a target figure, that is the minimum consistent with full ionization and relatively slow inter-diffusion of the axial and azimuthal magnetic fields. Assuming that the plasma is heated simply by resistive dissipation in the region of high current density, a value for β of the order of 0·2 is obtained. Using the pinch relation, the basic parameters of the discharge are then fixed: $N \sim 5.10^{18}$ electrons/cm, $T \sim 10^6$ °K, $I \sim 1{\cdot}5.10^6$ A . The physical size of the apparatus is determined by the heat loading on the wall of the torus and by the electric field requirements at the surface of the discharge. For the final stage of the experiment it is proposed to use a porcelain torus of 1 m bore and 6 m diameter. Facilities will be provided to enable the effect on surface instabilities of reversing the stabilizing field external to the discharge to be studied. For energy storage a condenser bank of 14 MJ at 100 kV is planned.

Bickerton reported on various experiments carried out at Harwell.

1. Experiments with Linear Pinch and Unpinch Systems (Reynolds and Aitken)

These experiments follow the original work of Lovberg who showed that the current sheath in a particular linear stabilized pinch is stable for a period of only 2 µs. The object of the experiments was firstly to confirm these results and secondly to determine the nature of the instability, in particular to distinguish between electrostatic and hydromagnetic instabilities.

The pinch tube consists of a quartz tube of 30 cm bore with a distance of 70 cm between the electrodes. Outside the quartz tube a brass tube acts as a return conductor for the discharge current and as a flux shield for the axial magnetic field. The unpinch tube is of the same dimensions and differs only in that the return current, instead of flowing along the outer flux shield, flows in a central axial copper rod insulated from the discharge by a quartz tube. The discharge therefore expands outwards from the rod

/793

towards the outer wall of the tube compressing the axial magnetic field against the flux shield, instead of contracting as in the pinch tube.

Both the pinch and unpinch geometries involve the balancing of two magnetic pressures with a relatively small plasma pressure in the intervening layer. Under these circumstances the current flows largely along the magnetic field lines, the local electric field is consequently parallel to the magnetic field and the situation is ripe for the production of runaway electrons. These runaways may be able to excite electrostatic instabilities and from this point of view the pinch and unpinch systems are the same. But from the point of view of hydromagnetic stability the two systems differ. In the unpinch system the azimuthal magnetic field lines curve away from the plasma, whereas in the pinch they curve towards the plasma. The unpinch system might therefore be expected to be more stable than the pinch. The following table compares the two systems:

	Pinch	Unpinch
Peak current	200 kA	100 kA
Initial axial field	1200 Gauss	1200 Gauss
Line density	2.10^{18}/cm	2.10^{18}/cm
Bennett temperature	4.10^{5} °K	10^{5} °K
Current rise time	3·5 μs	6 μs (25 μs)
$\frac{\text{Tube radius}}{\text{Discharge radius}}$	3	1·2
Stability time (in hydrogen and deuterium)	3 μs	12 μs (15 μs)

The line density is sufficiently high to prevent appreciable runaway and no serious attempt has therefore been made to detect this effect. Under these conditions the comparison being made is one of hydromagnetic stability.

Both systems give a thin current skin in the gas (1/5 of the tube radius), the current distribution being measured by means of small magnetic probes. Probe signals are not reproducible after 3 μs for the pinch tube indicating instability of the channel, a result which agrees with Lovberg's. The unpinch current sheath seems to be stable for a larger time (12 μs), but it must be noted that in the unpinch system the axial magnetic field is not strong enough for the outward expansion of the channel to be stopped at the same position in the tube as in the pinch system, but only when the channel approaches very closely the tube wall. A direct comparison of the two systems may not therefore be justified under these conditions.

At 12 μs the unpinch current has fallen to zero. Measurements of stability with currents of longer duration (and longer rise times) indicate that the stable time is still only 12 μs. It is possible that some instability is caused in the unpinch system by the curvature of the axial field lines near the electrodes, because the field is "frozen" into the electrode and cannot move outwards as it does in the central region of the tube. An experiment was therefore made in which the field at the ends of the tube was very much reduced relative to the central region to reduce or even reverse the curvature. The slightly longer stable time (15 μs) indicates that this approach might be worth future study.

It has not been possible to apply the Suydam stability criterion because of dynamic effects in the channel.

Further experiments are being prepared.

2. Toroidal Fast Pinch Experiment (Ashby and Paul)

The object of this experiment was two-fold; firstly to find out whether it is possible to produce a toroidal discharge in hydrogen in which the axial magnetic field is separated from the azimuthal field by a thin current sheath, and secondly to investigate the large amplitude hydromagnetic disturbances which arise when the velocity of collapse of the discharge exceeds the Alfvén speed in the undisturbed plasma.

The discharge is produced in a quartz torus of 64 cm diameter and 10 cm bore, surrounded by a closely fitting copper shell. The shell forms the primary and the gas the secondary of an air cored transformer. A slowly varying axial magnetic field of about 1 kGauss is applied first; the gas is then ionized and pre-heated by passing a current of the order of 10^4 A through it for 50-100 μs. The main discharge, produced by four 10 μF 30 kV capacitor banks, is then fired and the current rises to 100 kA in 1·5 μs when the capacitors are charged to 25 kV.

The main diagnostic techniques in use are coils to measure the voltage around the torus and gas current, and also magnetic probes to measure fields inside the torus. Most of the results have been obtained with 12·5 kV on the main bank, but some preliminary results have been obtained at 25 kV. These show the following:

a) When the main bank is fired at 12·5 kV, the current sheath with pre-heated gas is better than that obtained using unionized gas.

b) Marked radial oscillatory movement of the discharge is observed which, after the first cycle, roughly agrees with the predicted frequency for small signal radial oscillations of a channel in which magnetic forces predominate. This has been observed in hydrogen at 12–100 μ pressure.

c) At 25 kV with 25 μ of hydrogen the collapse velocity exceeds the Alfvén velocity and a disturbance propagates towards the centre of the discharge at a velocity exceeding both the collapse and Alfvén speeds.

d) Wall probes measuring B_z indicate that the discharge invariably goes unstable after one or two μs.

3. Fifty-Cycle Discharge in a 14-inch Torus (Davenport)

In this experiment a 14-inch bore transformer-type toroidal discharge was excited by direct connection to the A.C. mains. Observations were made of rectification, unassisted breakdown and X-ray emission.

a) Apparatus.

The characteristics of transformer-type discharges in a 14-inch bore, 42-inch diameter, aluminium torus, internally glass-enamelled, have been observed for hydrogen and other gases in the pressure range 10^{-3} to 10^{-4} mm Hg. Low electric fields of 0·1 to 0·02 V/cm were applied by connecting the transformer primary directly to the A.C. mains. The transformer core section was more than adequate to handle the upper limit of electric field, this being determined by the capacity of the available mains supply. Axial magnetic fields up to 1000 Gauss were used and in all experiments the gas currents were in the range of 1000 to 3000 A, which is well below the Kruskal limit.

b) Rectification.

Complete rectification occurred over a wide range of conditions, gas current flowing only when the applied electric and magnetic fields were in the same direction. This appears to be caused by slight perturbations of the axial magnetic field inherent in the geometry of the coil system, which produces a transverse component of field whose value at the outer torus wall is about 0·5 o/o of the axial component. By fitting a system of compensating coils it has been found possible to cancel and even to reverse the rectification.

c) Unassisted Breakdown.

Usually the discharge was found to require weak RF pre-ionization. Conditions have been found under which the rectifying discharge will start and continue indefinitely without pre-ionization.

d) X-ray Emission.

X-ray emission qualitatively similar to that occuring in the heating phase of the B1 stellarator has been observed and the presence of runaway electrons has been demonstrated.

e) Conducting Wall.

It has been suggested that the insulating wall is essential for rectification. That this is not so has been demonstrated by lining the torus with copper foil; rectification persists.

4. Alfvén Waves in Gas Discharges (Jephcott and Hartcastle)

These experiments have been carried out using toroidal discharges of 10 kA and 200 μs duration, in monoatomic gases at initial pressures of about 100 μ, and with axial fields in the range of 3-14 kGauss. Under these conditions the current density was nearly constant across the area of the torus (except close to the wall) and the discharge sufficiently quiescent for satisfactory signals to be obtained from magnetic probes.

Velocities have been measured over a range of B_z values. Curves giving $v = v(B_z)$ under various operating conditions, as well as experimental details can be found in Nature (June 13, 1959).

Except in the case of Xenon at low B_z (where the ion cyclotron frequency is appreciably lower than the wave frequency), the measured velocities of the waves as a function of B_z show agreement with theoretical analysis.

5. Ultra-Fast Pinch Experiment (Adlam)

This is a straight tube pinch experiment, where a cylindrical plasma containing an initial B_z field is compressed by a skin current in the z-direction. The experiment is different from others described in that the skin current is to be built up in a time short compared with the collapse time of the plasma. The electrical energy is obtained from a charged coaxial line and an attempt has been made to match the impedance of the line to that of the discharge. Using approximate theories for determining the collapse velocity, the impedance of the discharge has been calculated. The numerical values involved in the experiment are: voltage of pulse 24 kV, current of pulse 54 kV, length of discharge tube 12 cm, diameter of discharge tube 3 cm, initial value of B_z field 3000 Gauss. The calculated impedance of the discharge is $0{\cdot}44\,\Omega$.

6. Pre-Heat Experiment (Martin)

This experiment involves investigation of plasma characteristics of a strong pre-heating discharge. The experimental arrangement comprises a fused silica torus of 64 cm major diameter and 6:1 aspect ratio. A copper shell 1 mm thick encloses the silica except for two pumping tubes. A B_z coil of insulated wire is wound onto the copper shell. Most of the standard tools of plasma physics are to be used for the diagnostic measurements. The quantities of main interest are, besides the electron and ion temperatures, the degree of ionization, stability and impurity content.

7. Excitation of Plasma Oscillations (Stringer)

This is a theoretical attempt to investigate the mechanism of acceleration of electrons in a pinch experiment before they get randomized by collective interactions. It is also hoped to investigate whether the electric fields associated with any plasma oscillations excited by runaway electrons could lead to drift of the plasma across the containing magnetic field.

8. Plasma Cyclotron Radiation and Mirror Machines (Jukes)

This is another theoretical effort intended to examine the existing theory of cyclotron radiation from high temperature plasma and to determine the radiation loss from a plasma confining magnetic mirror machine. The losses have been compared to possible nuclear yields in a self-sustaining fusion reactor.

Thompson listed various theoretical approaches under consideration at Harwell.

1. Equilibrium Conditions

a) Stream function approach (Laing and Roberts).
b) Expansion in powers of $\frac{r_o}{r^2}$ (Whipple).
c) Transform coordinates (Whiteman).
d) Non hydromagnetic equilibrium (Walkinshaw).

2. Stability

a) Cylindrical configurations
    i) Suydam and Rosenbluth criteria (Tayler).
    ii) Laing's models.
    iii) Finite transport effects (Tayler).
b) RF stabilization
    i) Rotating fields (Tayler).
    ii) Knox configuration (Whipple).
c) Finite Larmor radius and surface instabilities (Hubbard).

3. Kinetic Theory

First order hydrodynamics and interchanges in magnetic shocks (rôle in surface instabilities).

4. Transport Effects

Bohm diffusion and transport coefficients.

5. Debye Shielding

Use of φ_n as coordinates in statistical mechanics.
Use of correlation functions.
Use of dielectric interactions.
Debye screening and Čerenkov effect.

6. Response of Plasma to RF Fields

Effect of density gradients across magnetic fields.

7. Production of Plasma

Electric field screening and rate of ionization (thetatron).

Ware reported on results obtained with Sceptre IIIA at A.E.I., Aldermaston.

1. Results Obtained with Sceptre III

The state of knowledge of the discharge in Sceptre III by August 1958 can be summarized as follows:

a) There was evidence that the discharge core was stable against gross wriggling for the duration of the pulse (600 μs), but there were still fluctuations present on the magnetic probe signals (10-20 o/o of the total signal) - and the streak photographs showed the presence of "bars" in the outer regions of the discharge.

b) The electron temperature was low, $T_e \approx 2.10^5\ {}^oK$.

c) The spectral lines of highly ionized impurities showed considerable Doppler broadening corresponding to a Maxwellian velocity distribution. If thermal motion were involved rather than turbulence, the ion temperatures would correspond to about $10^6\ {}^oK$.

d) The centre of mass of the reacting deuterons has a velocity component parallel to the gas current of about 4.10^7 cm/s.

2. Problems

From these results the questions which had to be answered were:

a) What is the cooling mechanism for the electrons?

b) What is the cause of the Doppler broadening? If it is a high ion temperature, then (since it had been expected that the ions would be heated mainly by collisions with the electrons and this would give $T_p \leqslant T_e$) what is the ion heating mechanism?

c) What is the cause of the "bars" seen on the streak photographs?

d) What is the accelerating mechanism causing nuclear reactions?

3. New Apparatus

At this stage Sceptre III was dismantled and modified to facilitate further measurements on the discharge. The main changes from Sceptre III to Sceptre IIIA are the following. Firstly, the coils producing the stabilizing magnetic field (B_ϕ) have been replaced by a new set of 208 single turn water cooled copper coils. The coils are supplied from a 315 kW, 3500 A D.C. generator and fields up to 2400 Gauss can be obtained. Secondly, two of the straight sections in the torus have been replaced by new sections, one of them containing a quartz window situated close to the tube wall. With the aid of mirrors mounted outside the window, the discharge can now be viewed tangentially as well as radially. The other section contains an aperture into which improved nuclear plate cameras can be fitted. In all other respects the apparatus is the same as Sceptre III. The same condenser bank has been used so far, the maximum voltage being 30 kV, which corresponds to 66 kJ.

4. Experimental Results

a) Current and Voltage.

The oscillograms taken show that the waveforms are the same as with Sceptre III.

b) Electron Temperature.

This has been measured from the absolute intensity of the C^{V} spectrum (central core of the discharge). The results show the electron temperature to be remarkably constant except for pressure variations.

c) Doppler Broadening.

Using the quartz window, a spectroscopic study has been made viewing the discharge in three directions. Firstly, it was found that the Doppler broadening of the ion spectral lines was independent of the direction of observation. This is one of the properties of high temperature broadening. However, a turbulent mass motion of the gas could be isotropic and yield similar Doppler broadening. Secondly, it was found with the tangential viewing that the spectral lines of highly ionized impurity atoms, in addition to their broadening, exhibit a small wavelength shift. This shift can only be explained by a Doppler effect and it indicates that the ions have a mean directed velocity superimposed on their random thermal motion. The direction of this velocity is parallel to the positive gas current.

d) X-ray Measurements.

The measurements were made using a small pinhole camera inserted a short distance into the discharge tube. It was found that the main sources of X-rays were the copper liners which cover the torus gaps. These liners do not only protrude into the tube, but have magnetic lines of force passing into them from the discharge space. Measurements with different thicknesses of metal foil covering the pinhole indicated a range of photon energies up to 8 keV. The X-ray intensity decreases with increase in photon energy. It has been possible to make only a very rough estimate of the energy content of the bombarding electrons causing these X-rays, but the energy appears too small to explain the bulk of the electron energy loss.

e) Magnetic Probe Measurements.

B_θ and B_ϕ measurements for peak current have been made and the analysis of the results leads to j_θ, j_ϕ and pressure plots. The results show that the discharge has a central core about 12 cm in diameter which carries most of the current. At the edge of this core j_ϕ drops abruptly to a low value and there is a pressure minimum. Outside this radius there is an annular region where both j_ϕ and pressure rise again. Near the inner wall there is a region where both j_ϕ and B_ϕ are negative. The values of $\dot{B}_\phi$ show that E_ϕ falls only slightly between the edge and the centre of the discharge. The electron temperature obtained from the electrical conductivity neglecting the presence of impurities is about 10^5 ^{o}K and rises slightly towards the centre. The electron heat conduction deduced from these results is inwards.

f) The "Bars".

When the discharge is running under clean conditions the only part of the tube which emits visible light is that between the discharge core and the wall. This light appears intermittently and on streak photographs is often seen as a series of bars of light at right angles to the streak direction. At the beginning of the half-cycle the bars move along the discharge tube in the opposite direction to the positive gas current with a velocity of the order of 10^6 cm/s. Later in the half-cycle the direction of movement is sometimes reversed. In order to elucidate the nature of the bars, experiments have been made with magnetic probes and streak photographs. In some of the cases a complete correlation has been obtained between the fluctuations on the dB_θ/dt waveform and the bars; the negative peak of each fluctuation corresponds to a bar passing the probe. In other cases, although the number of fluctuations was approximately equal to the number of bars in a given time interval, a detailed correlation between a given bar and a fluctuation appeared to be absent. However, the time resolution of the oscillograms is not really adequate at present.

Theoretical considerations suggest that the bars might be the result of a discharge instability and that they might be at the origin of the electron loss mechanism.

Niblett reported on thetatron experiments at AWRE, Aldermaston.

These experiments are concerned with the compression of a plasma using azimuthal currents. In the system known as thetatron, a rapidly rising axial magnetic field produced by a current in a single-turn coil is used to compress and confine the plasma. Interest in this configuration arises because it should possess greater hydromagnetic stability than the normal pinch using axial currents.

The experiments consist in discharging a low inductance condenser bank through a one-turn coil wrapped around a quartz tube containing gas at low pressure. The condenser bank (Maggi) has been designed for low inductance and its principal feature is that it employs 200 spark gap switches in parallel. The capacity of the bank is 100 μF, the working voltage 20-30 kV, and the inductance, including switches and leads, $5{\cdot}5.10^{-9}$ henries. There has been no attempt to give the magnetic field a mirror shape. A particular coil used in many experiments gave a peak magnetic field of $1{\cdot}1.10^5$ Gauss, the current being $1{\cdot}8.10^6$ A.

Discharges in air and deuterium at initial pressures in the range from 10 to 1000 μ have been studied with and without weak RF pre-ionization. Measurements of the variation of voltage, current and rate of change of current have been made and the discharge has been photographed with Kerr cell and high speed streak cameras. Using deuterium gas, time-resolved measurements of X-ray and neutron emission have been recorded. Neutrons are emitted at about peak current on the second and occasionally the third half-cycles. With an initial voltage of 30 kV and 100 μ pressure, the peak yield is of the order of 10^5 per discharge. Streak photographs show that the plasma is highly turbulent at neutron time.

A comprehensive series of streak photographs of the initial implosion process have been taken. These photographs suggest that the axial field penetrates the cold gas during the formation of the current sheath and that this field is subsequently trapped as the gas pinches in. The measured frequency of radial oscillations of the plasma is consistent (within about 20 o/o) with all the gas being trapped.

Experiments to study the thetatron configuration in a torus have begun, but results are not yet available, It is planned to measure the time for the plasma column to drift to the outer wall in the non-uniform toroidal field and to compare the results with theory. Attempts will then be made to inhibit the drift by an applied rotational transform.

Latham reported on recent work at the Imperial College, London.

Photographic work on a straightforward linear pinch in argon has recently been carried out. The pressure was 80-100 μ. Pyrex tubes of 15 cm diameter and 25 or 50 cm length have been used. The voltages were up to 5 kV and peak currents of 300 kA have been obtained. Observations were made (through a diametral slot in the anode) by means of a swept image converter using a sweep coil; the coil was provided by AWRE and gave speeds up to 3 cm/μs.

The results obtained show the usual collapsing current shell more or less following the snow-plough theory (Fig.5), at least in the first stages

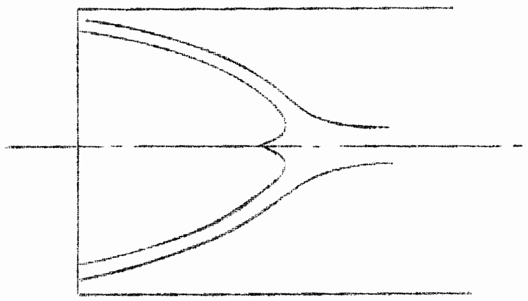

Fig. 5

of the collapse. Near the first pinch the collapse curve becomes flatter and there is a central region of luminosity a little before the main shell reaches the axis. No evidence has been found so far of this starting suddenly as might be expected on the basis of a shock wave preceding the shell. It just appears as if the particles have a velocity distribution and some reach the axis early causing some randomization and high light output before the main body reaches the axis.

After the first bounce, the photographs usually show a second bounce and then a fairly rapid break of the discharge with evidence of turbulent motion and droplet formation. This refers to the 50 cm long tube and about 2 kV on the discharge when the current oscillogram is more or less horizontal after the first pinch. On reducing the length to 25 cm and pushing the voltage up to 5 kV the current profile begins to rise after the first pinch and finally has the shape of Fig. 6. This has the effect of delaying the onset of the real turbulent break-up of the discharge and it can now last, well clear of the walls, for 20-30 μs increasing slowly in diameter. At this stage 50 kJ are being put into the discharge and one begins to observe the effects of radiation emitted from the pinch.

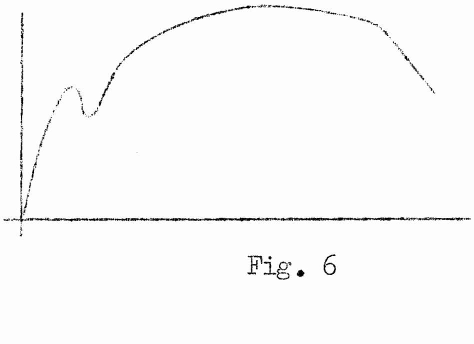

Fig. 6

The tube was covered except for the slit in the end with a black cloth to prevent stray light from the sides. This cloth begins to show surface burn marks showing the pattern of the return conductors-strips close to the glass. The inner surface of the glass must also get extremely hot and the streak photos show a second current shell formed at the walls at the time of the first pinch, coming in in the normal way and presumably contaminating the discharge with wall material. On some photos there is even evidence of this process being repeated a second time.

A set of conical copper liners were then tried, fitting inside the glass and overlapping, and held apart by rings of glass cord. They were extending the full length of the discharge tube, placed about 1 per cm and were about 1/3 mm thick. Surprisingly enough, this makes no first order difference to the formation of the current sheet, the picture being substantially identical to the straight pyrex tube pictures. However, the second current shell formed at the walls by the radiation from the first pinch has now disappeared. There are, however, some differences; the pinch appears broader as might be expected in view of the interference of the serrated walls, and the current pulse shows signs of a dip at the first pinch. The tube was opened up after about 100 discharges at 50 kJ and showed marked distortion of the cones, but the only evidence of arcing was on the copper surface where the distortion had made the cones actually touch. The glass cord spacers had been shaken loose and some had ends within the tube.

For an initial experiment this was found very encouraging. It establishes that a metal walled tube does not prevent the discharge from forming and in this case eliminates the major influx of gas from the walls caused by the radiation at the first pinch.

With end-viewing one gets an overall diameter, including irregularities in the discharge. The experiment will be extended to side-viewing at the higher inputs to see whether the previous droplet formation is still there.

The actual diameter of the discharge at its first pinch while still symmetrical should be a very interesting parameter. By careful density calibration of the films, the optical width to half light output has been measured in the region of the first pinch. For a tube diameter of 15 cm the half-width in the first stages of the pinch can be as small as 1-2 mm, slowly rising to perhaps 1 cm at the end of the very hot region. Maybe for the smallest widths one was looking at the tip of the hot region before the main current reached the axis, but it certainly looks as if compressions of 30:1 in linear dimensions are not unreasonable.

Allen summarized the Rome programme.

1. Plasma sheath transitions to study the properties of plasma boundaries in the presence of a magnetic field.
2. Compression of plasma using azimuthal currents.
3. Fast compression by θ-currents (orthogonal pinch effect).

A brief description of the apparatus as well as numerical details were given last time.

Brinkman summarized the theoretical work recently carried out by his group.

1. Bremsstrahlung (survey of approximations).
2. Motion of particles in an inhomogeneous magnetic field.
    a) analytical work.
    b) numerical work.
3. Rotating plasmas.

Linhart reported the results of an experiment on plasma-waveguides for cm waves.

The propagation of electromagnetic waves on cylinders of plasma has been investigated theoretically by several workers. Experimental conditions resembling the assumptions postulated by theoreticians have been attempted at by the CERN group. A cylinder of plasma is produced by a reflex discharge in argon at a pressure of a few times 10^{-4} mm Hg. The cylinder, of

1 cm radius approximately, is coaxial with a cylindrical cavity the radius of whose walls is 5•5 cm (Fig.7).

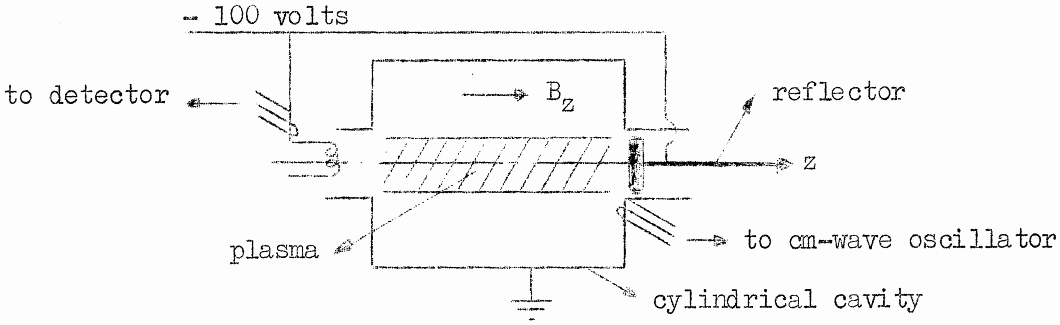

Fig. 7

The density of the plasma has been measured by Langmuir probes, collecting positive ion current, and by the shift of the resonant frequency of the cavity. The linear densities thus measured were between 10^{11} and 10^{12} particles/cm.

The microwave signal was introduced by a magnetic probe projecting through one of the endplates of the cylindrical cavity.

Three types of resonant modes were observed:

a) The usual resonant modes of the cylindrical cavity, somewhat detuned by the presence of the plasma column.

b) Coaxial modes, for which the plasma column plays the rôle of an inner conductor of a cylindrical line.

c) Specific plasma modes, i.e. electron waves guided by the plasma column.

Various probes were used to explore the field distribution of these modes, especially of three of them, namely the E_{012}, E_{013} and E_{014} modes.

The results are in good agreement with the simple theory worked out by I. Fainberg and J. Linhart two years ago.

<u>Dattner</u> reported on an experiment of plasma acceleration.

A condenser bank is discharged through a hydrogen gas between two concentric conductors (Fig.8). A disc of plasma is created and accelerated

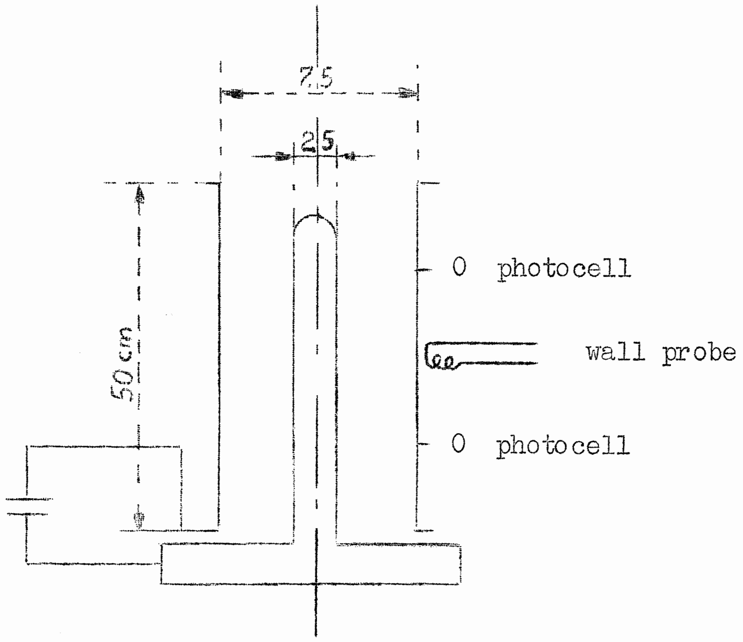

Fig. 8

along the axis of the coaxial system. The velocity of the luminescent front is measured by means of photocells situated along the discharge tube. The velocity of the current sheath and the current distribution within the sheath are measured by means of magnetic pick-up coils inserted in the wall of the outer conductor (the skin depth of the outer conductor is of the same order of magnitude as the thickness of its walls).

The two condenser banks used had maximum energies of 3000 J, rise times of 12 and 4 µs and maximum voltage 7 kV. The pressure was varied from 0·1 to 1 mm Hg.

Preliminary results are: the velocities obtained vary with voltage and pressure and are between 2 and 10 cm/s. The higher velocities were obtained with the faster condenser bank. For each condenser bank the velocity increases with voltage and decreases with pressure.

The current sheath is situated at the front of the luminescent region. The oscillograms from the coils inserted in the walls seem to indicate that instead of one current sheath one has two or even three, the spacing between them being of the order of sheath thickness, i.e. a few cm.

Agdur reported on work on microwave propagation.

This propagation has been studied in bounded and unbounded plasmas for arbitrary values of plasma density and D.C. magnetic field. Special attention has been given to the properties of slow waves, but fast waves and the transition between slow and fast waves have also been studied.

Propagation of slow waves in a plasma where the density varies in a direction perpendicular to propagation has been investigated in some detail and it has been shown that such inhomogeneities may have a very strong influence on the wave propagation, especially when $\Omega^2 = \Omega_{pe}^{(r)2} + \Omega_{ce}^2$, Ω being the signal frequency, Ω_{pe} the plasma frequency of the electrons, r the space coordinate and Ω_{ce} the gyromagnetic frequency of the electrons.

The propagation of slow waves in a plasma has been studied experimentally as a function of plasma density, D.C. magnetic field and excitation frequency. Interaction between fast electrons and slow waves has also been studied experimentally and the very strong coupling between the electrons and the waves shown theoretically has been observed. Both these experiments have been done in a mercury discharge plasma, but suitable apparatus is now in construction for a study of the phenomena in a caesium plasma.

Gibson reported on work on runaway electrons.

Experiments were made to determine the energy loss in toroidal discharges and to investigate the mechanism of runaway phenomena associated with the energy loss.

X-ray detection was used and the electron distribution causing them was inferred.

Three types of measurements were used, absorption measurements, pinhole camera experiments and scintillation techniques.

- - - - - - - -

E.R.

ER/gd

CERN/FSG/11 - Add. 1
4 September, 1959.

CERN STUDY GROUP ON FUSION

Fourth Meeting

Harwell - 18, 19 and 20 June 1959

- - - - - - -

Formation of a Journal for Plasma Physics

The International Atomic Energy Agency at Vienna had proposed the setting up of a new journal for plasma physics, particularly directed at controlled fusion. The Study Group were asked by the Chairman for their opinion on the necessity of such a new journal. The Study Group did not think that a new journal was necessary in view of the many outlets for papers on fusion and plasma physics in already existing periodicals, such as "Nuclear Instruments and Methods" and Part C of the "Journal of Nuclear Energy".

- - - - - - -

E.R.

ER/gd

PS/793 bis