to the Director, A.E.R.E., for permission to work at A.E.R.E., Harwell.

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Experimental Demonstration in the Laboratory of the Existence of Magneto-Hydrodynamic Waves in Ionized Helium*

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THIS laboratory has been investigating the properties of ionized gases at low pressures in a toroidal discharge tube where ion diffusion to the walls can be retarded by a magnetic field co-annular with the toroidal tube. The discharge is excited by a 2-microsecond pulse applied to a primary winding of 10 turns of wire on a pulse transformer core which links the toroid. The secondary of the pulse transformer is effectively the ionized gas in the toroidal discharge tube; the peak current in this gas under some circumstances goes as high as 8000 amperes. The densities of electrons and ions and the electron temperature can be measured in the afterglow period in this discharge tube by means of a probe which is connected mechanically to the amplifier of a synchroscope only during an "examining interval" of about 1000 microseconds. Except during this examining interval, which can be variably delayed with respect to the excitation pulse, the probe floats in the plasma and is decoupled from both the amplifier and the voltage source.

With a short probe (3-mm effective length) inserted into the region of high ion-density gradient near the tube wall, oscillations can be observed on synchroscope traces of both the positive ion current [Fig. 1(a)] and the electron current [Figs. 1(b) and 1(c)]. These oscillations are either subdued or absent when the probe is inserted to the center of the discharge tube. These oscillations are entirely absent when no dc magnetic field is present [Fig. 1(d)]. The synchroscope photographs represent the traces of several pulses on the same exposure. Although the phases of the oscillations are, in general, not coherent from pulse to pulse, it is nevertheless possible to delineate from the photographs oscillations involving several cycles of definite periods of approximately 100 microseconds. These oscillations in ion and electron density near the wall of the tube suggest the presence of standing magneto-hydrodynamic waves set up around the toroid whose length L is approximately 100 cm. The propagation velocity V of such a wave[1] is given by $V=H_0(1/4\pi\rho)^{\frac{1}{2}}$, where H_0 is the value of the dc magnetic field in gauss and ρ is the density of the gas. For a standing wave $L=n\lambda/2=nV/2\nu=nH_0/2\nu(4\pi\rho)^{\frac{1}{2}}$, so the frequency of the standing wave $\nu=nH_0/2L(4\pi\rho)^{\frac{1}{2}}$, where n is an integer. With our experimental conditions of $\rho=3\times10^{-9}$ g/cc and $H_0\cong400$ gauss the computed $\nu\cong400n/[2\times100\times(4\pi\times3\times10^{-9})^{\frac{1}{2}}]\cong10^4n$. If $n=1$ this value of the frequency ν agrees reasonably well with the observed frequency of 10^4 cycles/sec. Furthermore, if the wave is to be undamped to the extent that a standing wave can be set up in the length L, it can be computed from Alfven's relationship[1] that $LH_0>\pi^{\frac{1}{2}}c^2(\rho)^{\frac{1}{2}}/\sigma$, where σ is the conductivity of the gas in cgs units and c is the speed of light in cm/sec. If we take a reasonable value of $\sigma=10^{13}$ cgs units, the inequality is maintained for our circumstances, and we should expect to observe standing waves.

Attempts to demonstrate quantitatively the dependence of V on H_0 for these waves have not yet met with success in this toroid because of the difficulty of setting up standing wave patterns at several values of the field H_0. It has been observed qualitatively however, that at the higher values of H_0 it is frequently difficult to set up a good standing wave pattern and that the pattern presented contains noise of frequency higher than is generally observed at the lower values of H_0. The amplitude of the oscillations is lower with the higher values of H_0.

These oscillations in ionization density at the plasma periphery are ascribed to displacements associated with magneto-hydrodynamic waves. These oscillations have also been observed in H_2 and N_2.

Magneto-hydrodynamic waves very likely play a role[2] in increasing the rate of ion diffusion perpendicular to the magnetic field.

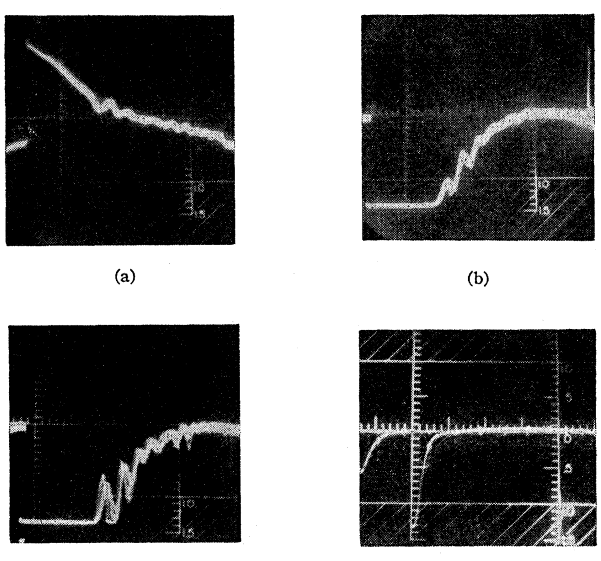

FIG. 1. Oscillations on current to probe in He at a pressure of 0.020 mm. The examining interval begins 600 microseconds after the excitation pulse. (a) Positive-ion current, $H_0=530$ gauss; (b) electron current, $H_0=530$ gauss; (c) electron current, $H_0=410$ gauss; (d) $H_0=0$, when no oscillations occur anywhere in the afterglow period.

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Acceleration of Beryllium and Carbon Ions in a Synchrocyclotron*

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NUCLEAR emulsions have been exposed to carbon and beryllium ions in the University of Chicago synchrocyclotron. Carbon ions of energies as high as 1.1 Bev have been directly observed in photographic plates. The acceleration of carbon and oxygen ions in the Berkeley 60-inch cyclotron has been previously reported.[1–5] In the present experiment CO_2 gas was introduced into the ion source of the Chicago cyclotron in place of the hydrogen which is normally used. In order to eliminate the large number of $(H_2)^+$ ions originating from the water vapor inside the cyclotron tank, the upper frequency limit of the oscillator and the magnetic field were adjusted so that $(H_2)^+$ would not be accelerated near the center of the cyclotron. However, under these conditions, carbon ions with 5 electrons removed and Be atoms completely stripped could be accelerated. The beryllium ions are

Table I. Number of δ-rays along C and Be tracks.

Ions	No. of δ-rays per 100 microns at δ-ray max.	Residual range in microns from point of δ-ray max.	No. of δ-rays per 100 microns at 1000 microns from end of track
${}_4Be^9$	32 ± 6	565 ± 60	22 ± 6
${}_6C^{12}$	67 ± 6	225 ± 60	58 ± 6

presumably due to the evaporation of an internal beryllium target which normally is subject to intense high energy proton bombardment.

Ilford C-2 and G-5 plates of various thicknesses were wrapped in black paper and mounted on the end of a probe which made it possible to expose the plates at various radii in the cyclotron. Multiple scattering measurements of the tracks in the emulsion at a cyclotron radius of 40 inches indicated a large intensity of low energy protons. The origin of these protons can be accounted for as being due to the acceleration of $(H_2)^+$ and $(H_3)^+$ at smaller radii. Due to the existing lower frequency limit of the synchro-cyclotron oscillator, completely stripped carbon ions were not observed at radii greater than 65 inches and beryllium ions at radii larger than 50 inches.

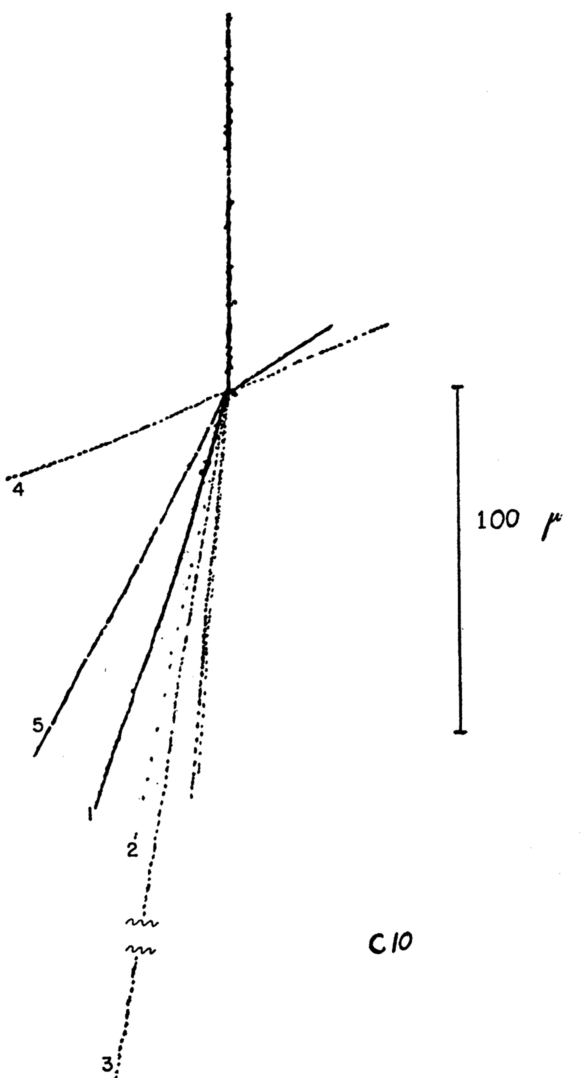

Fig. 1. A projection drawing of a collision of a carbon nucleus in a C-2 emulsion.

A study of the δ-rays along the C and Be tracks has been made in electron sensitive G-5 plates. δ-rays of energies greater than about 14 Kev (1.5–2.0 microns) were counted. The results of this study are summarized in Table I. At maximum δ-ray intensity the number of δ-rays as a function of atomic number Z, is expected to be proportional to Z^2. The experimental data as given in Table I are in agreement, within the experimental errors, with this dependence. It is also to be noted that the residual range, from the position of the δ-ray maximum, decreases with increasing Z. The change in the number of δ-rays, per unit length, with residual range was found to be in general agreement with the theoretical calculations.[6]

Multiple scattering measurements of 7 of the carbon nuclei were made by the sagitta method.[7] For a cell length of 250 microns both theory[8] and experiment indicated that the scattering factor[9] is almost independent of energy from 1.1 to 0.1 Bev. The average value of the scattering factor in this energy range was found to be 24.8 ± 1.4, which is in agreement with the theoretical value[8] of 26.4.

An example of a nuclear collision of an artificially accelerated carbon nucleus with a nucleus in the emulsion is shown in Fig. 1, in which 9 particles were emitted. The total energy of the carbon nucleus was about 750 Mev and corresponded to an energy per nucleon of about 60 Mev at the point where the star was formed. Track 1 did not stop in the emulsion and was produced by a heavy fragment which could be lithium. Tracks 2 and 4 were most probably produced by protons of energies of about 50 Mev and 3.8 Mev, respectively. Track 3 which was close to 10,000 microns long was probably produced by an α-particle of energy of about 210 Mev. Track 5 was due to an α-particle of 17 Mev.

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Gamma-Ray Yield from the Proton Bombardment of Boron

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The gamma-ray yield in the forward direction resulting from the proton bombardment of natural boron has been measured in the energy region between 130 kev and 1 Mev. Gamma-rays were detected with a NaI scintillation counter; the discriminator was set so that the x-ray background from the accelerator was not detected. Proton beams, of from one to two microamperes, from the recently completed University of Kentucky electrostatic generator were focused on the targets. The beam energy was controlled by varying the corona current by use of an error signal from slits placed after the 90° magnetic analyzer. The energy calibration was obtained by measuring the magnet current at the known[1] gamma-ray resonances of fluorine below 1 Mev. By following a definite magnet recycling procedure, repeated runs indicate the energy determinations to be accurate to ±0.25 percent. For