GENERAL ATOMIC DIVISION
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EXPERIMENTAL INVESTIGATION OF THE FUNDAMENTAL MODES OF A COLLISIONLESS PLASMA

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INTRODUCTION

During the current period we have identified the previously observed waves as cyclotron waves on drifting beams in the plasma. These beams have been eliminated and with improved techniques we now observe the plasma wave between the electron cyclotron frequency and the upper hybrid frequency. We have now accumulated enough data on these waves to constitute a substantial experiment. A paper entitled "Cyclotron Waves in a Collisionless Plasma", by C. B. Wharton and J. H. Malmberg, was presented at the APS Annual Meeting of the Division of Plasma Physics, New York, November 4, 1964. Portions of the data given in that talk, plus subsequent results, are included in this report.

Beam Waves

The dispersion curves in the last quarterly report showed waves near the electron cyclotron frequency[1]. At the time of that report we suspected that these waves were cyclotron resonance waves on drifting electron streams. We have been able to show that these beams were due to secondary electrons generated by ions plowing into the wave launching helix. In particular, the group velocity of these waves can be accurately computed from the difference in the potential of the helix and the potential of the plasma. That is, the group velocity is just equal to the velocity of the secondary electrons in the plasma. The existence of these beam-waves in the plasma is an interesting effect but not the one we set out to look for, so we have eliminated them by eliminating the helix and using probes to launch the waves. This reduced the wave launching efficiency, but by using improved instrumentation, we have still retained sufficient resolution to find cyclotron waves. Secondary electrons from the ion trap suppressor grid are still a minor problem for wave propagation in the upstream direction, leading to abnormal damping, and in some cases even wave growth. Their current density is too low to cause an instability, and no effect on downstream propagation is evident.

Cyclotron Waves

At least three (and perhaps more) distinct waves having resonances (wavenumber becoming large) at or near the electron cyclotron frequency have been catalogued. Two waves lie above the cyclotron frequency. One has a $v_{\phi} > c$ and is a forward wave. The other is a "slow wave", having a phase that retards with frequency, i.e., a backward wave. The fast wave apparently is an electromagnetic waveguide mode, perturbed by the plasma. The slow

[1]Quarterly Report No. 2, GACD-5716, Fig. 1

wave apparently is the C_{01} cyclotron wave[2,3], having a propagation cutoff at the upper hybrid frequency, $f_{uh} = (f_b^2 + f_p^2)^{1/2}$. It is heavily damped at wavelengths shorter than about 10 cm and we have not yet been successful in plotting out the entire dispersion curve. Quantitative damping-length measurements are now in progress. Partial dispersion curves are shown in Figs. 1, 2, and 3.

Below the cyclotron frequency there appear to be several waves. The fastest of these, fairly certainly, is the plasma-perturbed TE_{mn} waveguide mode mentioned above. Its dispersion curve matches that for a waveguide whose cross-section is 1/10 filled with plasma. We have a plasma column of about 2 cm diameter inside a 12 cm diameter tube, which, accounting for radial density gradients, is a reasonable fit. The dispersion for this wave is very similar to that for a whistler[4].

The other "cyclotron waves" may be higher modes, that is, those having circumferential field variations. One of them, shown in Fig. 1, between 250-340 Mc, seems to have a cutoff frequency compatable with the C_{11} cyclotron wave. If so, it should exhibit Faraday rotation, and we are currently looking for this effect. Unfortunately, the wave is heavily damped and can be followed for only a wavelength or two, making measurements very difficult. The "whistler" mentioned above would also have Faraday rotation, except that the ordinary wave component is cut off by the

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[2] Trivelpiece, A. W. and R. W. Gould, J. Appl. Phys. 30, 1784 (1954).

[3] Bevc, V. and T. E. Everhart, J. Electronics and Control 13, 185 (1962).

[4] Heald, M. A. and C. B. Wharton, Plasma Diagnostics with Microwaves, John Wiley and Sons (1965).

waveguide cutoff, leaving only the elliptically polarized extraordinary component. No evidence for polarization rotation of this wave has been found.

The "lower branch" waves, the conventional spacecharge waves of a warm, finite plasma column, have been extensively investigated at General Atomic and elsewhere, and reported on in the literature[2,5]. We have plotted the dispersion curves here, since we use these waves in a diagnostic manner, to aid us in understanding the cyclotron wave characteristics.

The three figures show effects of various plasma densities and cyclotron frequencies on the cyclotron family of waves. Ideally, we should also study the effects of various electron temperatures, but this is difficult to achieve. Recently we have tried adding an impurity of argon to the hydrogen, in an attempt to decrease T_e from its usual 10 to 15 eV. Evidence that the decrease occurs is meager, but looks encouraging. The (collisionless) damping of the lower branch can be decreased drastically; we will now look at the effects on the upper branch (cyclotron family) to see if there is also collisionless damping of these waves.

Financial

Approximately $62,000 has been expended or committed on this project to date.

[5] Malmberg, J. H. and C. B. Wharton, Phys. Rev. Lett. 13, 184 (1964).

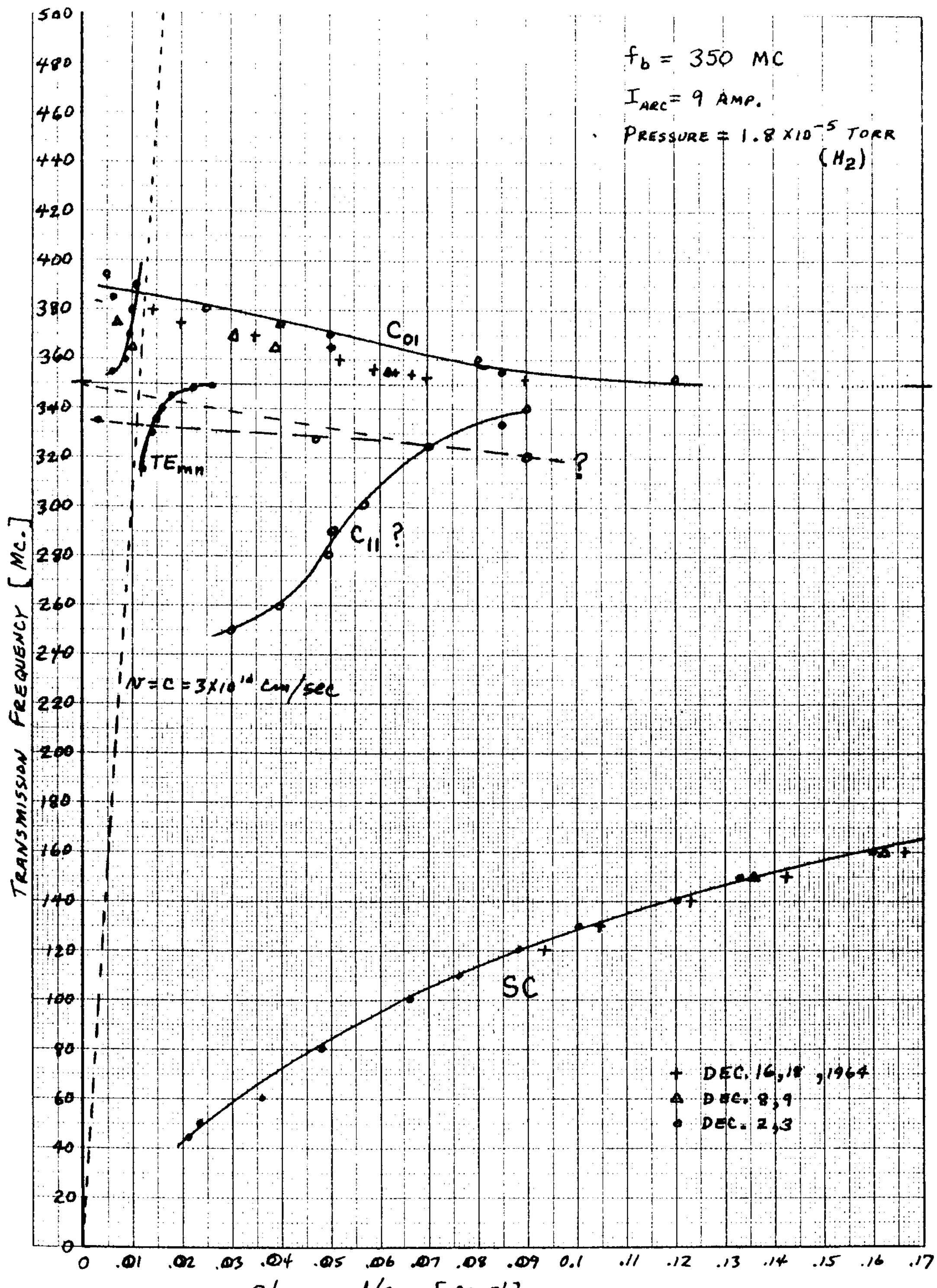

Fig. 1--ω-β diagrams for waves in the collisionless H_2 plasma, over the frequency range 0 - 500 Mc. Cyclotron frequency f_b was 350 Mc and plasma density n_e was approximately $4.2 \times 10^8/cm^3$.

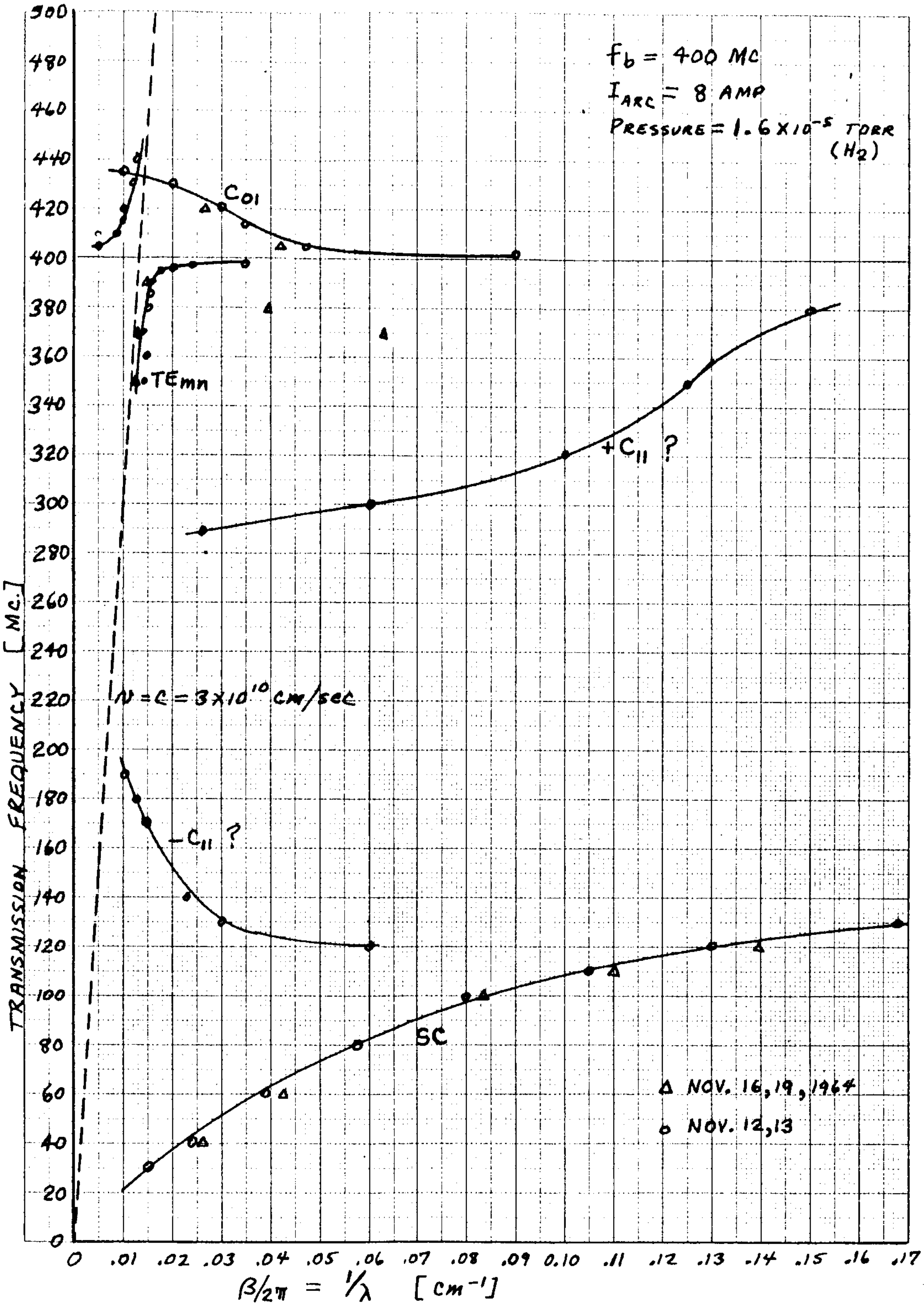

Fig. 2--ω-β diagrams as in Fig. 1, but $f_b \approx 400$ Mc, $n_e \approx 3.9 \times 10^8/cm^3$.

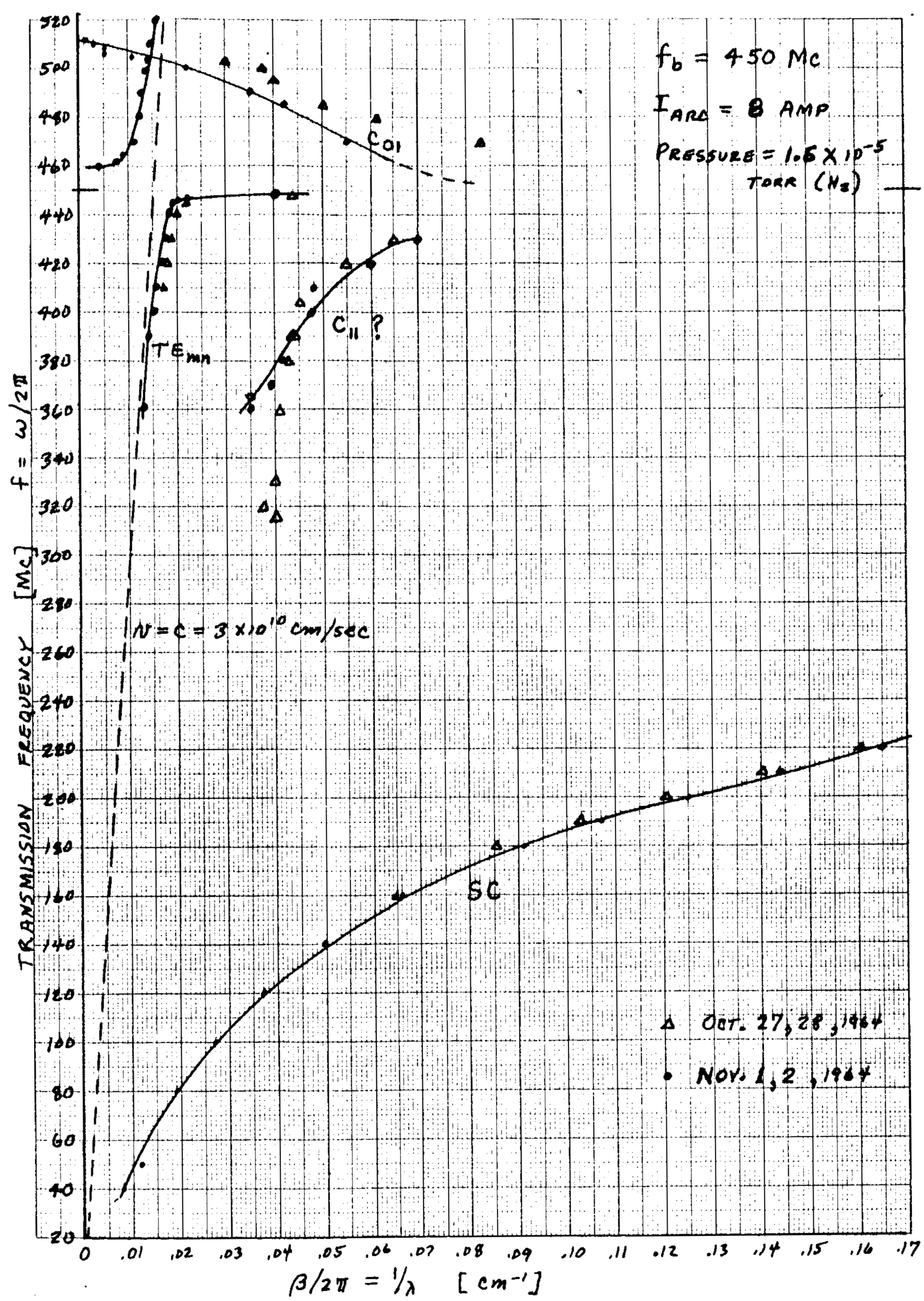

Fig. 3--ω-β diagrams as in Fig. 1, but f_b = 450 Mc, $n_e \approx 7.1 \times 10^8/cm^3$.