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ABSTRACT

Multiple two- and three- pulse cyclotron echoes have been observed in a weakly ionized Cs plasma. Comparison of the experimental results with calculations confirms the e^- - Cs velocity dependent collision cross-section as the non-linear echo forming mechanism.

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Cyclotron echoes have been previously observed in weakly ionized plasmas of rare gases or Nitrogen,[1,2] and in a strongly ionized Cs plasma.[3] In the former case, the non-linear mechanism causing echoes was attributed to electron-neutral collisions,[1,4] and in the latter case the echo formation was attributed to electron-ion collisions.[3] In the present letter we describe the observation of cyclotron echoes in a weakly ionized Cs plasma.

In order to calculate the cyclotron echo amplitude expected, a numerical integration was performed following the analysis of Herrmann et al.[1], and using the total scattering cross section reported by Brode.[5] The quantity calculated[1] was the macroscopic polarization at the time of the first echo, μe, of the electron gas following excitation at the cyclotron frequency by two microwave pulses:

$$\mu e = v_o e^{-\nu_c(v_o)\tau} \int_{-\infty}^{\infty} g(\Omega) e^{-\nu_c(\Omega)\tau} [e^{2i\Omega\tau} + e^{i\Omega\tau}] d\Omega, \qquad (1)$$

where $g(\Omega)$ is the spectral distribution function, Ω is the distance in frequency from the center of the electron line, τ is the pulse spacing, v_o is the electron velocity after a single microwave pulse, and $\nu_c(v)$ is the collision frequency as a function of velocity. This latter quantity depends on Ω after the second pulse through the dependence of the electron velocity on Ω. The numerical calculation indicated an echo amplitude vs τ of roughly the same shape for e^- - Cs collisions as that for e^- -A collisions. However, the Cs echo was calculated to give 10^{-2} times the power of the Argon echo for the same electron-densities. This difference is due to the relative weakness of the

Ramsauer minimum for e^- - Cs collisions compared with that for e^- -A collisions. It is interesting to note, however, that even for a collision cross-section independent of velocity, cyclotron echoes can occur, since the collision frequency is the relevant quantity in Eq. (1). Even if the Ramsauer minimum is absent, cyclotron echoes are still expected because ν_c has a velocity dependence (unless accidentally $\sigma \propto 1/v$) by virtue of the relation $\nu_c = N\sigma v$, where N is the neutral atom density, σ is the scattering cross section, and v is essentially the electron velocity. This fact is shown experimentally by the observation[1] of echoes in a Ne plasma, since the e^- - Ne collision cross section is practically constant over the velocity range of interest. Calculations also indicate that the echo amplitude as a function of pulse spacing for Cs and A afterglow plasmas have the same decay rate if the relative pressures considered are 10^{-4} Torr for Cs and 10^{-2} Torr for A, since the average scattering cross section for Cs is roughly two orders of magnitude larger than that for A over the electron velocity range of interest.

The transmitter for 10 nsec 10 Watt X-band microwave pulses is essentially identical to that described by Hill et al.[1] The microwave pulses were propagated from a horn in a direction perpendicular to the static magnetic field of 3 kgauss, through an oven in the field containing the Cs cell, and into a receiver horn on the other side of the oven. The receiver was a low noise gated travelling wave tube amplifier followed by a superheterodyne receiver with a 250 MHz IF and a 100 MHz bandwidth. The signal-to-noise ratio could be enhanced by using a Tektronix 3S76 sampling scope plug-in as a boxcar integrator with

very narrow gate width.

The Cs cell consisted of a discharge bulb kept at 190°C and a side arm containing a Cs puddle at a temperature which could be varied between 70°C and 100°C. The cell was prepared by pumping it out to 10^{-7} Torr, baking it for 12 hours at 430°C, filling it with Cs, and sealing it off. Most of the data was taken with a side-arm temperature of 85°C, indicating a Cs pressure in the discharge bulb of 2×10^{-4} Torr. The discharge was produced by a 2 msec 22 MHz pulse. The electron density could then be varied by starting the microwave sequence at various times in the afterglow. This scheme yielded reproducible plasmas for side-arm temperatures greater than 79°C. At this temperature, the Cs pressure was below 10^{-4} Torr, and any further decrease in pressure resulted in damping of the discharge. The purity of the cell was determined by looking at the spectrum of the discharge with a Jarrel-Ash $\frac{1}{4}$ meter spectrometer, and a photomultiplier. The two Cs lines at 4555 Å and 4593 Å were observed with signal-to-noise of 10:1 and 5:1 respectively. No other lines were observed over the photomultiplier sensitivity range of 4000 - 5000 Å. Since the Cs - e^- scattering cross section is much larger than the electron scattering cross section for any suspected impurity gases, the lack of any other spectral lines is good indication that the observed echoes do not arise from collisions between electrons and something other than Cs.

The possibility of electron-ion collisions dominating the echo-mechanism, as in the case of the strongly ionized Cs plasma,[3] was eliminated by starting the microwave pulse sequence later than 0.3 msec into the afterglow. After this time the upper hybrid resonance was independent of the time of a microwave pulse, indicating that the

plasma frequency was much smaller than the cyclotron frequency. This latter fact implies the electron density was less than 10^9 cm^{-3}. Since at this density the screened Coulomb momentum-change cross section is about $10^{-14}(cm^2)$,[6] which is the same order of magnitude as the electron-neutral cross-section, and the gas is less than 0.1% ionized, the Coulomb collisions must be of negligible importance.

Multiple two-pulse echoes were observed (Fig. 1) and measured as a function of the microwave pulse spacing (Fig. 2). In Fig. 2, the echo power calculated from Eq. (1) was multiplied by an overall scale factor since the number of electrons contributing to the echo was unknown. The echo envelope does not behave exactly as the simple theory,[1] presumably because diffusion along flux lines was neglected. However, the maximum echo power was 10^{-1} microwatt, which is just 10^{-2} times the maximum echo power in A using the same apparatus and the same method of achieving an electron density of $\sim 10^9$. The decay time of the two-pulse echo was found to be about 30 - 50 nsec, within a factor of two of the rate calculated by the simple theory. Also, the maximum two-pulse echo amplitude saturated for 1 watt incident pulses. At this power level, v_o for the electrons was about 5×10^7 cm/sec, or 0.85 $(e.v.)^{1/2}$. The calculated v_o for maximum echo amplitude was 0.8 $(e.v.)^{1/2}$.

Multiple three pulse echoes were also observed and measured as a function of the pulse spacings. The decay rate for these echoes as the time of the third pulse was varied with a fixed 200 nsec two-pulse separation was found to be about 20 μsec, in accordance with the model presented by Harp et al.[2]

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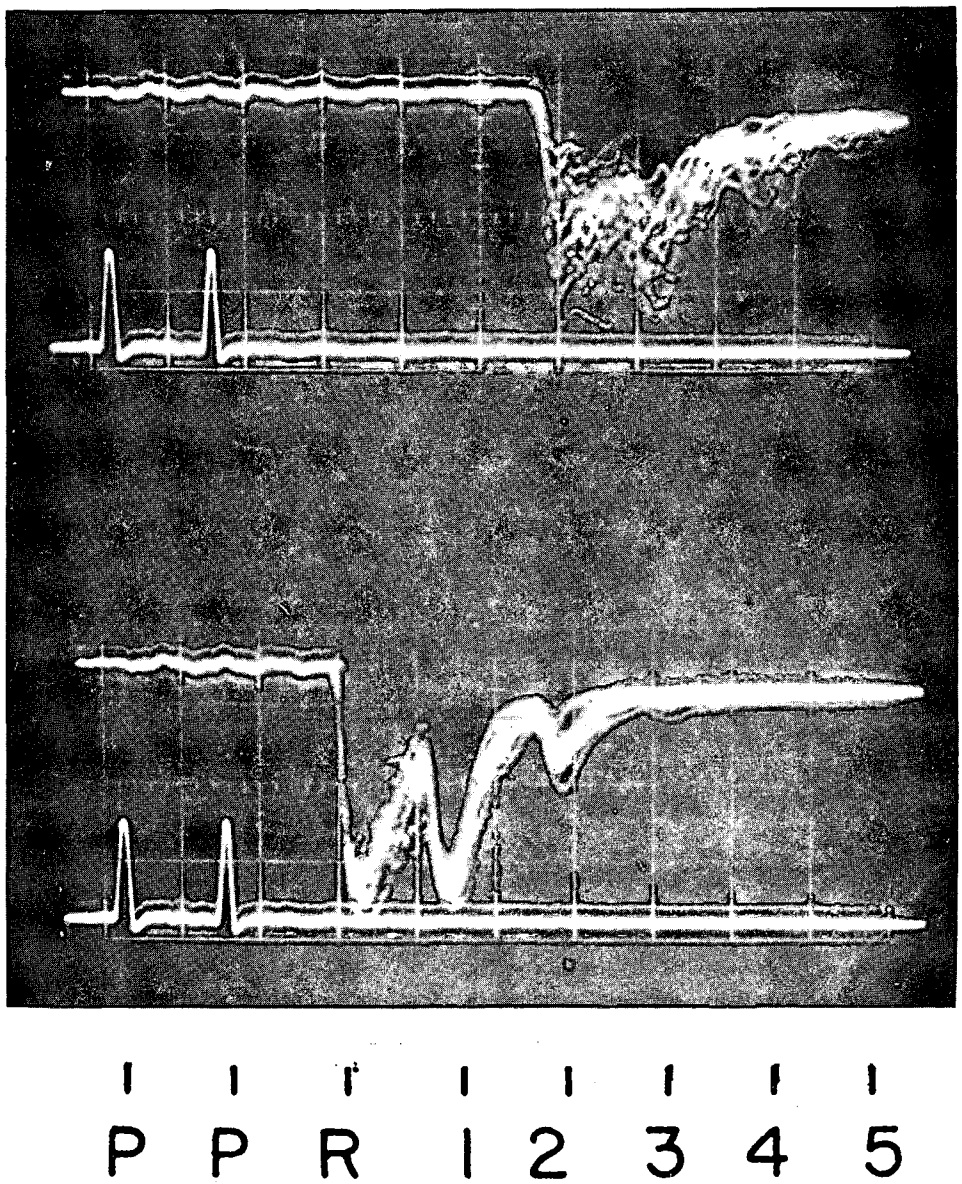
FIGURE CAPTIONS

Fig. 1. Multiple two pulse echoes. P: input microwave pulses; R: receiver turn-on; 1-5: echoes. The time scale is 100 nsec/div, and there is approximately 150 nsec delay between the lower and upper traces. a: 20db receiver attenuation; b: 0db receiver attenuation

Fig. 2. Calculated (solid line) and measured two-pulse echo envelope for a Cs density of 1.5×10^{-4} Torr, and microwave pulse power of 1/2 watt.



XBB 698-5434

Fig. 1

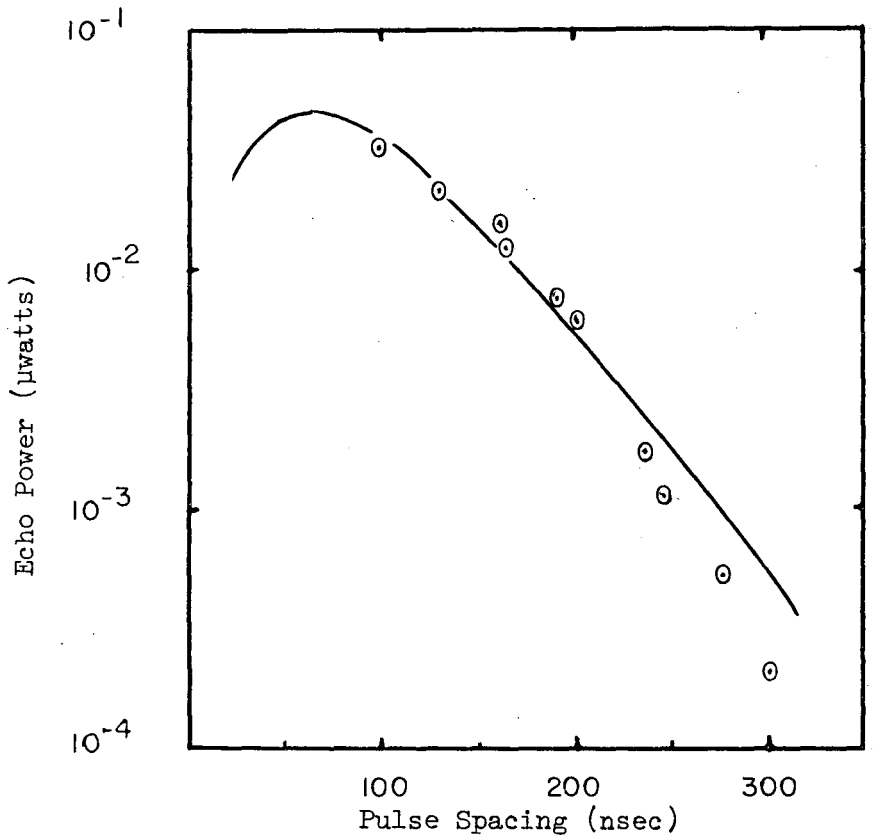

10^{-1}
10^{-2}
10^{-3}
10^{-4}
Echo Power (μwatts)
100
200
300
Pulse Spacing (nsec)

Fig. 2

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