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Abstract. Results are given of an investigation into an electron avalanche produced by microwaves at the electron cyclotron resonance frequency in the presence of crossed electric and magnetic fields.

The acceleration of electrons arising from the interaction with microwaves at the electron cyclotron frequency may be employed for the production of plasmas in magnetic traps (Arisimov *et al.* 1967, Budnikov *et al.* 1967).

In the course of experiments on cyclotron resonance of free electrons of 5 to 10 keV energy, an avalanche phenomenon has been observed which is initiated by cyclotron-accelerated secondary electrons.

Electrons gyrating in a homogeneous magnetic field $\boldsymbol{B}$ (0, 0, B) are drifted through a 9·5 GHz rectangular microwave cavity designed so that a dc electric field $\boldsymbol{E}$ (0, E, 0) can be maintained across it. The transverse drift velocity in the x direction is given by $(\boldsymbol{E}\times\boldsymbol{B})/(\boldsymbol{B}\,.\,\boldsymbol{B})$. A video spectrometer is used to observe the resulting cyclotron resonance signal which consists of the typical frequency-shifted emission–absorption profile (Schneider 1960, 1959, Hirschfield *et al.* 1965) of fast electrons and a small absorption peak associated with secondary electrons of low energy. A detailed description of the apparatus will be given elsewhere.

When the microwave power incident on the cavity is increased above, and the dc field across the cavity reduced below certain critical values, the onset of nonlinear behaviour of the absorption signal is observed. Beyond these critical points the height of the absorption peak associated with the slow electrons becomes strongly dependent on both the microwave power and the dc voltage across the cavity. When the microwave power is increased slightly the low energy resonance changes rapidly from the small peak arising from a steady flow of a moderate number of secondary electrons to an absorption signal so large that the detection circuit becomes saturated. A similar effect is seen when the potential difference across the cavity is reduced thereby causing an increase in the transit time of the electrons through the cavity. Figure 1 shows the rapid increase in resonance absorption with increasing microwave

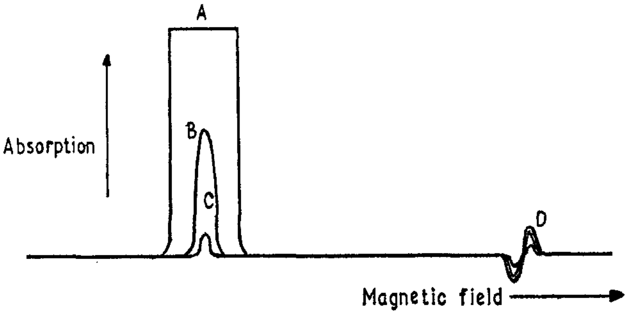

Figure 1. Microwave absorption profiles for different incident powers. A, absorption by avalanche electrons at a power of 1 mW. B, absorption by avalanche electrons at a power of 0·8 mW. C, absorption by injected electrons (low energy) at a power of 0·64 mW. D, absorption by injected electrons (high energy) at a power of 1 mW, 0·8 mW and 0·64 mW.

power. For very high microwave power and low drift voltage a similar nonlinear resonant cyclotron absorption can be observed without any injection of electrons. This is somewhat erratic and presumably initiated by accidental electrons from cosmic ray and radioactive background.

This phenomenon is obviously the result of electron multiplication by an ionization avalanche in which cyclotron acceleration forms the principal energy gain process. Low energy electrons which undergo resonant absorption gain energy at a rate which depends on the strength of the microwave field and the interaction time. If the electrons attain sufficient energy for impact ionization of residual gas in the cavity, a potentially unstable situation is produced and an electron avalanche may be formed.

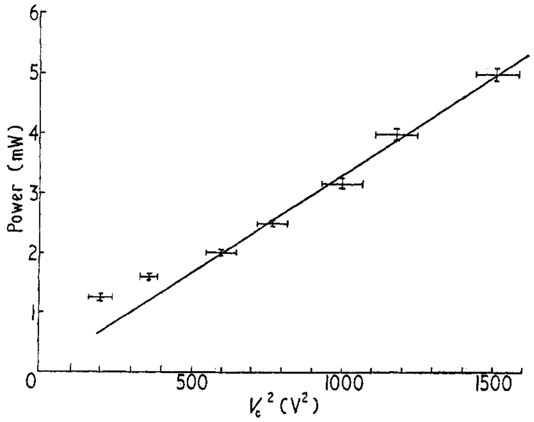

Figure 2. The square of the critical potential difference across the cavity against microwave power. The lower two points do not lie on the curve because of electric field fringing effects inherent in the construction of the electron injection svstem.

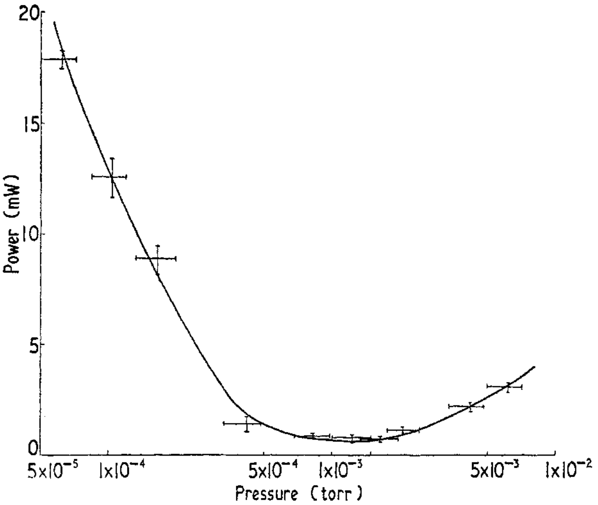

Figure 3. Critical microwave power against pressure. The theoretical minimum of this curve occurs at a pressure of $1{\cdot}5 \times 10^{-3}$ torr.

To verify this, the incident power P_i supplied to the cavity was varied by means of a calibrated microwave attenuator and the corresponding critical dc potential across the cavity V_c below which the avalanche started was noted in each case. The experimental results (shown in figure 2) obtained at pressures of 5×10^{-4} torr show the dependence

$$P_i \propto V_c^2.$$

As another test the microwave power necessary to initiate the electron avalanche was measured as a function of pressure between 5×10^{-5} torr and 5×10^{-3} torr. The results are shown in figure 3.

A detailed theoretical description of the avalanche process (to be published) correctly predicts the square law dependence and the minimum in the power against pressure curve as obtained in the experiment. Further experimental and theoretical work on the avalanche effect is in progress.

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Research Laboratory for Solid State Physics,
School of Physics,
University of Newcastle upon Tyne,
Newcastle upon Tyne, England.

F. Watt
J. W. Hand
E. E. Schneider†
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Instabilities in perpendicular collisionless shock waves

Abstract. A comparison of the ion acoustic instability with the $\boldsymbol{E} \times \boldsymbol{B}$ electron drift instability leads to predictions concerning observations of enhanced fluctuations in perpendicular collisionless shock waves.

There have been several observations of enhanced fluctuations within shock waves propagating perpendicular to an external magnetic field in a plasma (Paul *et al.* 1969, Daughney *et al.* 1970, Chodura *et al.* 1970). Several theoretical investigations stimulated by the papers of Krall and Book (1969 a, 1969 b) have examined the role of the $\boldsymbol{E} \times \boldsymbol{B}$ electron drift instability as a source of these enhanced fluctuations. The basic picture consists of magnetized electrons drifting relative to unmagnetized ions; only electrostatic waves are considered. The electric field arises owing to charge separation in the shock.

Wong (1970) was the first to obtain a correct solution of the linear dispersion relation for this instability, in the limiting case of zero ion temperature and propagation perpendicular to the magnetic field. Biskamp (1970) was the first to point out that

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† At present on leave at the Physikalisches Institut der Universität Frieburg i.B., Germany.