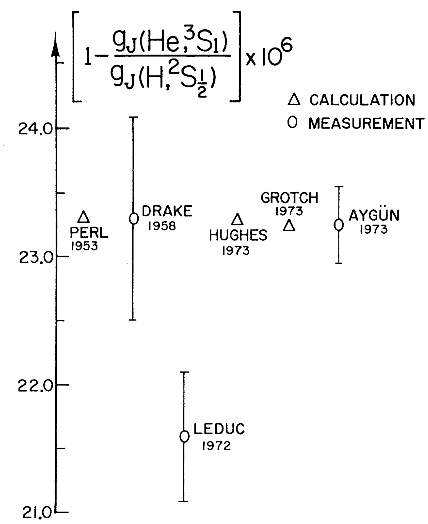


FIG. 3. Experimental and theoretical determinations of the He-H $g$-factor ratio. The values for the quantity $a$ (Table I) are the following: from Ref. 2 (1953), $a=23.3$; Ref. 5 (1958), $a=23.3(8)$; Ref. 1 (1972), $a=21.6(5)$; Ref. 4 (1973), $a=23.29$; Ref. 3 (1973), $a=23.212$; this work (1973), $a=23.25(30)$.

The error we assign to our result reflects our estimate of the residual systematic error arising from all sources.

The present state of both experiment and theory for the helium-hydrogen $g$-factor ratio is shown in Fig. 3. As can be seen, the agreement between the theoretical results and all atomic-beam measurements is very good. The discrepancy between these results and the value obtained by Leduc, Laloë, and Brossel, however, remains unexplained.

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# Microwave Emission from an Anisotropy Instability in a High-Current Relativistic Electron Beam

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A momentum anisotropy, created by injecting an electrostatically unneutralized annular electron beam through various foils, is shown experimentally to lead to high-power microwave emission. The radiation occurs at a frequency such that the phase velocities of cyclotron waves on the beam and the $TE_{01}$ mode in the guide are equal.

Recent work on the application of high-current relativistic electron beams to microwave generation[1-3] has been centered on the injection of the beams through a rippled magnetic field. The results developed show that the most probable explanation of the microwave generation is associated with the interaction of a cyclotron wave and a wave-guide mode. The injection through the rippled field serves the purpose of tailoring the particle distribution function to provide transverse motion of the beam electrons. The present experiment was designed to investigate the role of anisotropy in the particle distribution function as a source of free energy to drive the instabil-

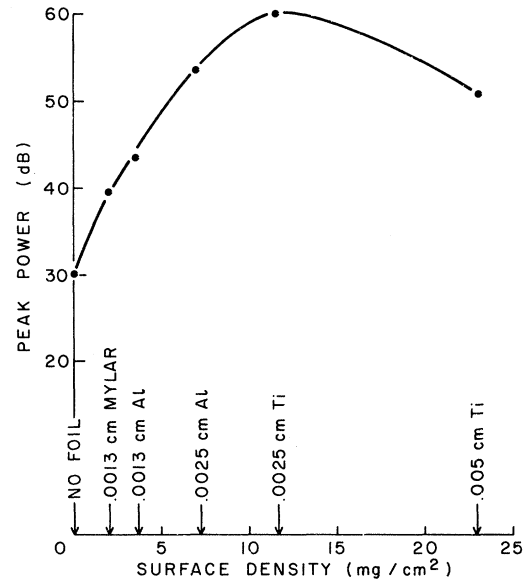


FIG. 1. Microwave signal intensity as a function of the surface density of the scattering foil.

ity. The instability occurs when the perpendicular energy spread exceeds the parallel energy spread.

In this experiment we used a 6-Ω pulse line at 300 keV giving injection currents of about 35 kA. The beam, which was produced in a foil-less diode, had a diameter of 3.6 cm and a thickness of 0.2 cm. The drift tube was 5.0 cm in diameter and approximately 55 cm long. The beam "temperature" was controlled by injecting the beam through a foil approximately 10 cm from the diode. The electrons in traversing the foil were multiply scattered. In the beam frame the average transverse energy gained by this scattering exceeds the parallel energy and hence creates the required anisotropy. In all cases the beam was guided by an axial magnetic field which ran to the tube wall prior to the tube end (i.e., it formed a beam dump) and the base pressure in the drift tube (wave guide) was held below $5\times 10^{-5}$ Torr.

The experiment consisted of monitoring the microwave emission as a function of the guide magnetic field strength. Fields in the range 4–8 kG were used. The intensity was measured with a calibrated detector, and the frequency from the dispersal of the signal through a 100-m run of wave guide. With the exception of emission close to the guide cutoff in the $TE_{01}$ mode, the signal was always narrow band and showed the same radiated frequency for each foil thickness (to within about ±0.4 GHz). The frequency could be

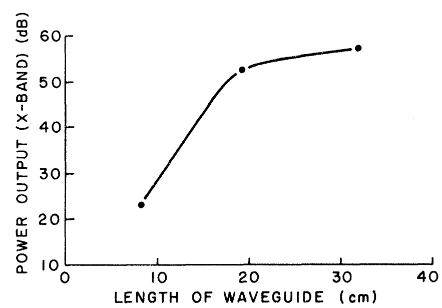


FIG. 2. Microwave power as a function of the length of the homogeneous magnetic field section after the foil. A 1-mil titanium foil was used as the scatterer; the axial-guide field strength was 6.5 kG.

tuned through the $X$ band (8.4–12.4 GHz) by changing the guide field strength. Within the limits of experimental accuracy the frequency of the observed radiation was such that the phase velocities of the cyclotron wave $\omega - kv = \Omega$ and the wave-guide mode $\omega^2 - \omega_{co}^2 - k^2c^2 = 0$ were equal. The interaction occured as a backward wave at a frequency

$$\omega = \frac{\Omega}{1-\beta^2}\left\{1 - \beta\left[1-(1-\beta^2)\frac{\omega_{co}^2}{\Omega^2}\right]^{1/2}\right\}, \qquad (1)$$

where $\Omega = eB/\gamma m$, $\beta = v/c$ is the normalized electron drift velocity, and $\omega_{co}$ the cutoff frequency of the wave guide.

The intensity of the signal only varied very slightly throughout the receiver bandwidth ($X$ band) and is plotted in Fig. 1 as a function of the surface density of the scatterer. The peak signal intensity (~20 MW) is comparable to that found in the rippled-field experiment.[3] The

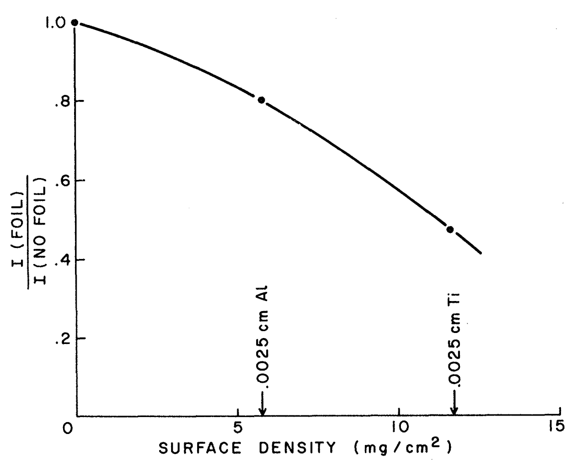


FIG. 3. Effect of the multiple scattering on the beam drift current compared to the current (9 kA) in the absence of a foil.

TABLE I. Variation of peak microwave power with mean scattering angle (due to the foil) and temperature anisotropy calculated in the *laboratory frame*. The inherent scattering in the diode is not included in the mean scattering angle. Assuming that the beam thickness is due to the transverse energy of the electrons places an upper limit on the ratio of the transverse to parallel energy in the absence of a foil, $W_\perp/W_\parallel \lesssim 0.12$. Note that the temperature anisotropy in the beam frame is larger than that found in the laboratory frame.

| Thickness and type of foil | Mean scattering angle (deg) | $\langle W_\perp\rangle/\langle W_\parallel\rangle$ | Peak microwave power (dB) |
|---|---|---|---|
| No foil | ⋯ | ⋯ | 30 |
| 0.5-mil Mylar | 8 | 0.025 | 40 |
| 0.5-mil aluminum | 16 | 0.1 | 45 |
| 1-mil aluminum | 25 | 0.24 | 53 |

growth of the signal with axial length of homogeneous field after the foil is shown in Fig. 2. The origin of the abscissas is arbitrary. As can be seen from this figure the growth rate is at least 3 dB/cm. To check that the microwave signal is mainly due to the change in the transverse energy of the system and not in part associated with changes in the beam current, this was also monitored. The results for the different foil thickness are shown in Fig. 3. The peak beam current in the absence of a foil is 9 kA.

The mean scattering angle for the foils used is given in Table I. Values are limited to the 1-mil aluminum and thinner. Under these conditions the scattered particle distribution is Gaussian and the particle loses very little energy in the scattering. We also compute the energy anisotropy in the laboratory frame using the mean scattering angle $\bar{\theta}$ and assuming a scattered electron distribution function of the form

$$f(p, \theta) = \delta(p - p_0)\exp(-\pi\theta^2/4\bar{\theta}^2), \qquad (2)$$

where $p$ is the momentum of the particle. As can be seen from the table the expected anisotropy is present. Clearly, the assumption of an initially zero-temperature beam is invalid so the anisotropy measure $W_\perp/W_\parallel$ must be regarded as semiquantitative only. The scattering process does, however, clearly increase the transverse energy spread of the beam to a greater extent than the parallel spread. The correlation between the increase in anisotropy and the radiated power is unmistakable and provides a clear identification of the source of instability causing the radiation. Preliminary calculations of this mechanism have been made by Manheimer and Ott.[4]

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