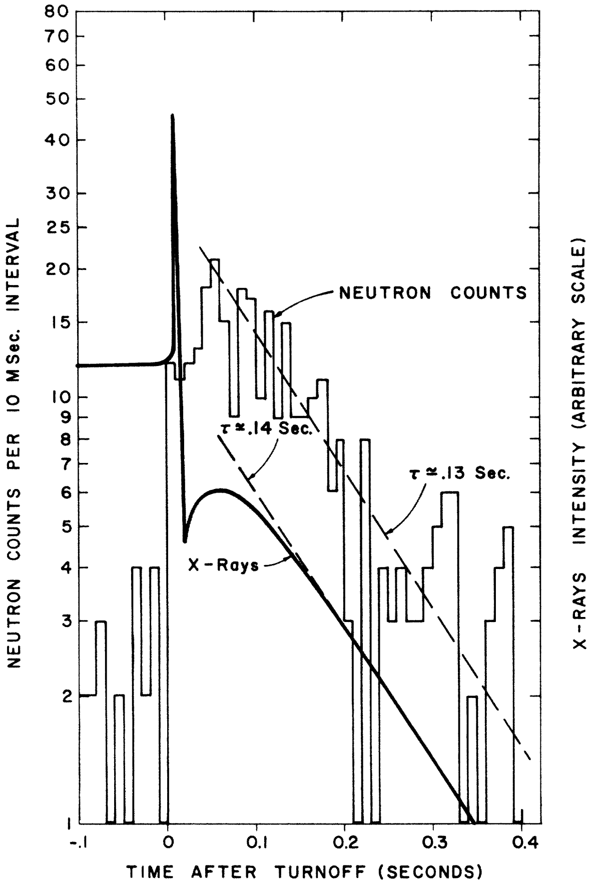

FIG. 3. The neutron counting rate and hard x-ray intensity from the PTF at microwave power turnoff. The hard x-ray counter is shielded from the plasma by 2 in. of lead. Neutron counts from 25 turnoffs were summed for improved statistics.

of $10^4$ cm$^3$, it is estimated that a high-energy ($\gtrsim 3$ MeV) electron population of $\sim 10^9/\text{cm}^3$ is required for the observed neutron emission rate. This requires only a small fraction of the electrons to be in the energy group which produces the neutrons and is in substantial agreement with the observed x-ray flux measurements.

Figure 3 shows the neutron counts as a function of time with microwave power turnoff. It is observed that the neutron counting rate rises about an order of magnitude ~50 msec after power turnoff. A typical hard x-ray decay is also shown. The neutron counting rate and the x-ray intensity both show a peak at ~50 msec and both have approximately the same decay time of 130-140 msec.

The authors are indebted to Dr. A. H. Snell for his continued interest and support. They also wish to acknowledge conscientious technical assistance from R. L. Livesey, M. Maskewitz, and M. W. McGuffin.

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[1] M. C. Becker, R. A. Dandl, H. O. Eason, A. C. England, R. J. Kerr, and W. B. Ard, Suppl. Nucl. Fusion Part 1, 345 (1962).

[2] We gratefully acknowledge the supporting effort of W. S. Lyon and co-workers of the Analytical Chemistry Division of Oak Ridge National Laboratory for the chemical processing and low-level activation measurement.

[3] R. T. Bramblett, R. I. Ewing, and T. W. Bonner, Nucl. Instr. and Methods 9, 1 (1960); W. R. Burrus, Neutron Physics Division Annual Progress Report ORNL-3360, 1962 (unpublished).

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# THOMSON SCATTERING OF OPTICAL RADIATION FROM AN ELECTRON BEAM*

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Using the apparatus indicated in Fig. 1, we have observed scattering of optical radiation from an electron beam. The experiment reported is of a preliminary nature prior to attempting the more difficult observation of scattering from the electrons in a plasma which, if successful, will yield valuable information on various plasma parameters.

Light from a ruby laser was focused to intersect an electron beam at right angles, and the scattered radiation was observed at an angle $\theta = 65°$ with respect to this beam. The laser produced bursts of energy of 20 joules and 800 $\mu$sec duration at wavelength 6934 Å. An electron density estimated at $\sim 5 \times 10^9$ cm$^{-3}$ was produced by magnetically focus-

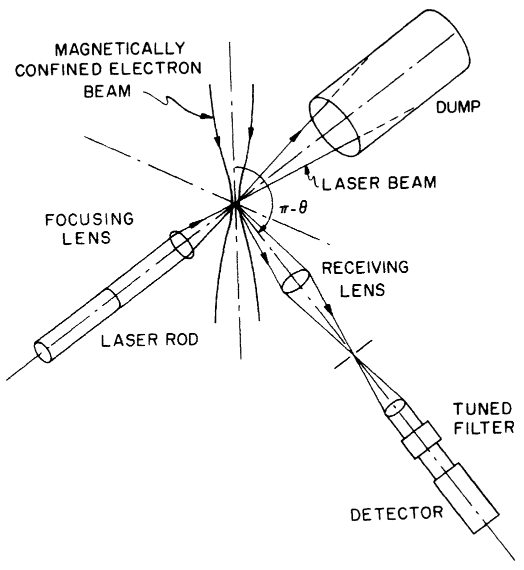

FIG. 1. Simplified diagram of the apparatus.

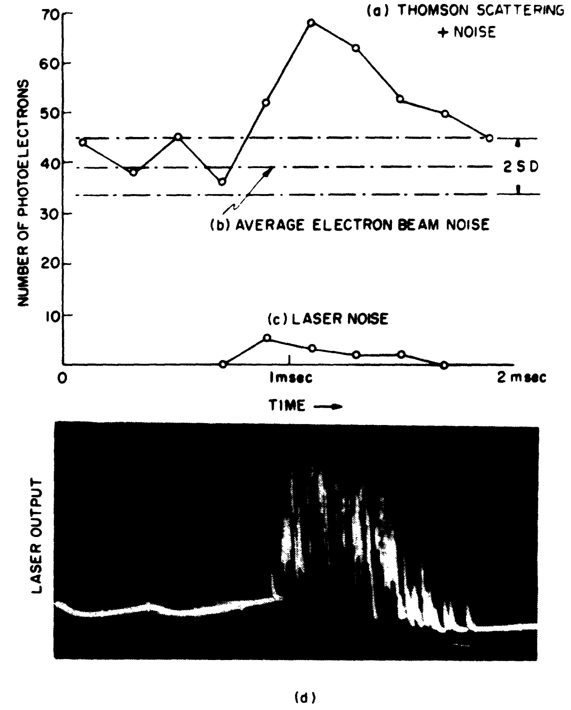

FIG. 2. Number of photoelectrons in successive 0.2-msec intervals (summed over 36 successive trials) due (a) to Thomson scattering plus noise and (c) to laser light scattered into the receiver in the absence of the electron beam. (b) is the average electron beam noise and (d) an oscillogram of the laser output.

ing a 2-kV, 75-mA electron beam. The polarization of the incident light was parallel to the axis of the electron beam.

The scattered radiation from a volume of 2-mm diameter was collected by the receiving lens which subtended an angle of $4.9\times10^{-2}$ steradians at the point of intersection of the laser and electron beams. After passage through an iris (to limit the field of view) and a system of filters, this radiation whose intensity was $10^{-18}$ of the laser output was detected by a photomultiplier with an S20 response, cooled to liquid $N_2$ temperature. The interference filters enabled us to reject the laser light scattered from the walls of the vacuum system, and accept only the scattered radiation which was Doppler-shifted by 259 Å. The bandwidth was limited to approximately 10 Å in order to reduce the background illumination from the electron gun. Oscilloscope traces of 2-msec duration of the photomultiplier output were obtained for the following three cases: (a) "signal plus noise," i.e., the laser beam impinging on the electron beam; (b) "electron-beam noise," i.e., light from the filament plus possible excitation of residual gas by the beam; (c) "laser noise," i.e., the laser light scattered into the receiver in the absence of the electron beam. As the photomultiplier dark current could be ignored, the sum of the photoelectron counts in (b) and (c) gave the total noise. Hence the difference between (a), and (b) plus (c) is a measure of the signal which is due to Thomson scattering. Many such groups of oscillograms were taken. The average value of this difference and its standard deviation are given below for three series of trials:

| Number of trials | Average Thomson photoelectrons | Standard deviation |
|---|---|---|
| 15 | 3.4 | 1.14 |
| 21 | 1.85 | 0.90 |
| 22 | 5.8 | 1.85 |

The variation in the average count for the three series is caused by changes in alignment. In addition, for the last series there was a 20% increase in the laser output, and the focusing of the electron beam was improved. As the quantum efficiency of the photocathode is 5% and the Thomson scattering cross section is $6.7\times10^{-25}$ cm$^2$, the expected number of photoelectrons within our bandwidth for the first two series of results is 3.1.

Figure 2 shows, for the first two series of trials, (a) the total number of photoelectrons observed in successive 0.2-msec intervals, (b) the average noise level that is due to the electron beam and its standard deviation, (c) the contribution from the "laser noise," and (d) an oscilloscope trace of the laser output.

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# POINT-BY-POINT MAPPING OF THE FERMI SURFACE

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The recently discovered phenomenon of magnetoplasma oscillations or helicons in metals[1-5] suggests a new method to determine the shape of the Fermi surface which for simple shapes should permit a point-by-point mapping of the surface. The helicons are observed in the limit when $\omega_c\tau \gg 1$, where $\omega_c$ is the lowest cyclotron frequency of the electrons and $\tau$ is their relaxation lifetime. In this limit and for the wavelengths that have been experimentally excited, the attenuation of these oscillations is small. However, if frequencies higher than those already observed but still much less than $\omega_c$ are excited, a new mechanism for absorption of these oscillations should appear. The wavelength of the oscillations at which this new attenuation mechanism appears depends on the geometric property of the Fermi surface and, in particular, may depend on the geometric property of a single point of this surface.

The physical origin of this attenuation can be easily understood. If in the metal a helicon of frequency $\omega$ and wave number $k_H$ propagating along the magnetic field is excited, then an electron of average velocity $\bar{v}_H$ along the magnetic field experiences, because of the usual Doppler shift, a frequency

$$\omega' = \omega \pm \bar{v}_H k_H. \tag{1}$$

If $\omega'$ coincides with the cyclotron frequency of the electron $\omega_c$, the absorption of the energy of the helicon by the electron will occur. In metals an estimate of the frequency $\omega$ at which this absorption will occur indicates that $\omega \ll \omega_c$, and thus absorption occurs when

$$\omega_c = \bar{v}_H k_H \tag{1'}$$

is satisfied for some electrons in the metal. The theory of this Doppler-shifted absorption has already been given for simple models of solids[6,7] and plasmas.[8] The form in which (1′) can be expressed for an arbitrarily shaped Fermi surface will be given here.

Experimentally it is possible to measure both $\omega$ and $k_H$ of the helicon. However, only $k_H$ enters in (1′), and thus experimentally one obtains information only on the ratio $\omega_c/\bar{v}_H$. The effect of the magnetic field, in a semiclassical picture, is to cause the electrons to move in the orbits in reciprocal space ($k$ space) determined by the intersection of planes normal to the magnetic field and the Fermi surface, and satisfying the equation[9]

$$\hbar(d\vec{k}/dt) = e\vec{v}\times\vec{H}. \tag{2}$$

The period of revolution of an electron $T$ is obtained directly from (2) to be

$$T = \frac{\hbar}{eH}\oint\frac{dk_t}{v_\perp}, \tag{3}$$

where $dk_t$ is an element in reciprocal space tangent to the orbit, $v_\perp$ is the instantaneous component of the velocity of the electron in the plane normal to $H$, and the integration is around the orbit. The average velocity of an electron along $H$, $\bar{v}_H$, is given by

$$\bar{v}_H = \frac{\hbar}{eHT}\oint\frac{v_H dk_t}{v_\perp}, \tag{4}$$

where $v_H$ is the instantaneous component of velocity of the electron along $H$. Since $\omega_c = 2\pi/T$, a combination of (4) and (1′) gives that

$$k_H = 2\pi eH\left(\hbar\oint\frac{v_H}{v_\perp}dk_t\right)^{-1}. \tag{5}$$

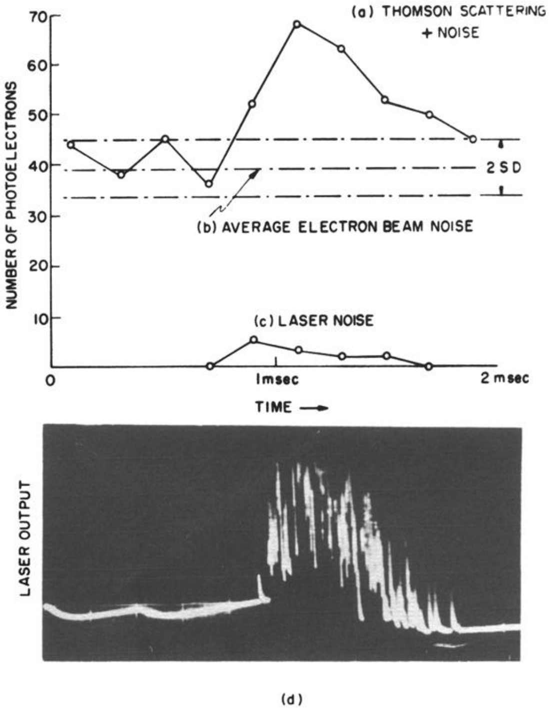

FIG. 2. Number of photoelectrons in successive 0.2-msec intervals (summed over 36 successive trials) due (a) to Thomson scattering plus noise and (c) to laser light scattered into the receiver in the absence of the electron beam. (b) is the average electron beam noise and (d) an oscillogram of the laser output.