MEASUREMENT OF THE POLARIZATION OF SYNCHROTRON RADIATION*

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The radiation emitted by electrons accelerated in a synchrotron has been investigated theoretically[1,2] and its spectrum and angular distribution have been measured.[3] It has an important astrophysical aspect since there is strong evidence that the light of the Crab Nebula has its origin in high-energy electrons moving through a strong magnetic field. Measurements on the continuous spectrum of the Crab Nebula have shown the light to be partly linearly polarized.[4] However, at this time one assumed that synchrotron radiation was linearly polarized. Recently Westfold[5] has shown for electrons moving at an angle α to a magnetic field and Bethe[6] for electrons in a synchrotron that the radiation is elliptically polarized, the ratio between major and minor axes depending on the angle ψ between direction of observation and the synchrotron plane. This makes it desirable to measure the polarization of synchrotron radiation from a terrestrial source.

The amplitude of light whose plane of polarization lies in the synchrotron plane is[6]

$$J_x = -\frac{ec}{\pi\sqrt{3}}\, i x^2 K_{2/3}\left(\frac{\omega}{3\omega_0}x^3\right),$$

and of that with plane of polarization perpendicular to it,

$$J_\perp = -\frac{ec}{\pi\sqrt{3}}\, x\psi K_{1/3}\left(\frac{\omega}{3\omega_0}x^3\right).$$

Here $x=(\psi^2+\gamma^{-2})^{1/2}$ with $\gamma = 1/(1-v^2/c^2)^{1/2}$, where v is the velocity of the electrons, c that of light, the K's are modified Bessel functions of the second kind, ω is the angular frequency of the observed synchrotron radiation, and ω_0 that of the electrons in the synchrotron. i indicates a phase difference of $\pi/2$ between the two amplitudes, which means elliptical polarization with the limits of linear polarization at $\psi=0$ and circular polarization at very large angles where $x=\psi$ and $K_{1/3}$ and $K_{2/3}$ have the same asymptotic behavior.

We have measured for both directions of polarization the variation of intensity with the angle with respect to the synchrotron plane, of the light emitted during the acceleration process at the Cornell synchrotron with peak energy 700 Mev. The apparatus used is shown in Fig. 1. The light

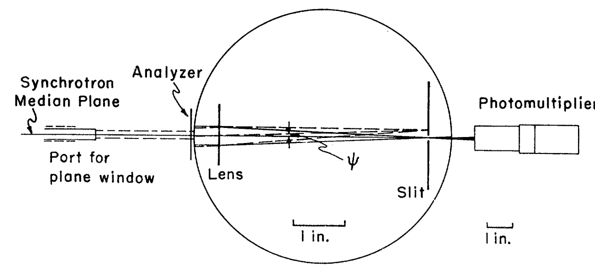

FIG. 1. Side view of light path through the apparatus.

coming through the plane window in the vacuum chamber is focused by a lens with 7.8-inch focal length. Light emitted at the same angle ψ forms a horizontal line in the focal plane. There we have a horizontal slit, mounted on a vernier caliper, which enables fine vertical movement. Thus we select with the slit position certain angles of emission. To determine the direction of polarization we insert a polaroid filter as analyzer in front of the focusing lens. The light is detected with an RCA-6342 photomultiplier, the anode current being read directly on a microammeter. At the end of the accelerating process the glass of the phototube fluoresces due to scattered electrons and their bremsstrahlung. The slit width and light filter are chosen to keep the signal large compared to this background. A yellow filter in front of the photomultiplier cuts the spectrum off at about 4500 A; the upper limit is given by the response of the tube. The slit width was 4 mils or 0.5 milliradian.

The result is shown in Fig. 2; the curve is the theoretical intensity with $\omega = 2\pi c/(5000\text{ A})$ and $\omega_0 = 2\pi\times 10.8\times 10^6\text{ sec}^{-1}$. The difference between the theoretical curve and the experimental points is due to oscillation of the electrons, the bandwidth of the radiation, and the finite slit-width, all these effects being intrinsically more pronounced in the perpendicular component. The experimental points are slightly asymmetrical, which is probably caused by a change of inclination of the central orbit during the cycle. To integrate the total intensity in the two directions of polarization, we measured the intensity with full width of the slit (1/8 inch). The result $J_x^2/J_\perp^2 = 3.45\pm 0.08$ is a little higher than the theoretical

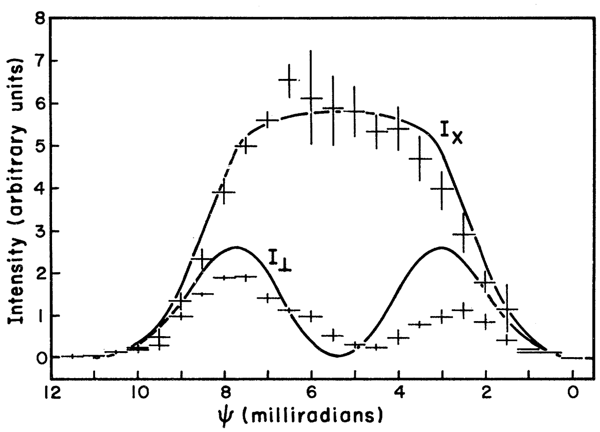

FIG. 2. Experimental and theoretical intensities of the two polarization components of synchrotron radiation plotted as a function of the angle.

value of 3.

To check the phase relation between J_x and $J_\perp$, a quarter-wavelength plate for the Hg 5461A line was inserted between window and analyzer. We placed the slit at 11 milliradians and opened it 3.8 milliradians. At this position the intensities were $I_x = 19.5$ units, $I_\perp = 13$ units. Inserting the quarter-wave plate and adjusting the analyzer at 45° between the two directions, gave for the maximum position 27 units, for the minimum 3. Thus the nearly circularly polarized light was converted into nearly linearly polarized light, which shows that the derived phase relation is correct.

The measurement of the magnitude and the angular dependence of the polarization show good agreement with the theory in its general shape. Since our measurement integrates J_x^2 and $J_\perp^2$ for one cycle and over all electrons, which might have an asymmetrical angular distribution changing with time, there are deviations in the details. The sensitivity to angular changes of the central orbit could enable one to make very fine beam studies.

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PLASMA STABILITY AND BOUNDARY CONDITION

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Recently, the validity of the classical theory of diffusion of charged particles across a magnetic field has been extensively discussed.[1-10] In the experiment made by Lehnert[1,7] agreement with the classical theory was found for magnetic fields weaker than a certain critical value B_c, beyond which this theory was observed not to be valid. The present note shows that this phenomenon can be explained by an instability of the wall sheath. The experiments[1,5-7,10] indicate that this instability causes the plasma to diffuse across the magnetic field much more rapidly than predicted by the classical theory.

Bohm's[3] criterion for a stable wall sheath formation is

$$v_i' \geq (kT_e/m_i)^{1/2}, \tag{1}$$

where v_i' is the ion velocity normal to the wall on entering the sheath, k is Boltzmann's constant, T_e is the electron temperature, and m_i is the ion mass. In ordinary gas discharges[1,5-7,11] it can be shown that this criterion remains approximately valid when the effect of a magnetic field (of the order of B_c) is taken into account.

Here it will be postulated that the plasma becomes unstable when the boundary condition Eq. (1) is not satisfied because v_i' can be reduced