# *POLARIZATION PROPERTIES OF SYNCHROTRON RADIATION FROM HIGH-ENERGY ELECTRONS*

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Submitted to JETP editor June 21, 1962

J. Exptl. Theoret. Phys. (U.S.S.R.) **43**, 1653-1656 (November, 1962)

High speed photography was used to obtain data on the ratios of the intensities and the angular distributions of both polarization components of the radiation emitted by electrons accelerated in a 680-MeV synchrotron. The relation between the real angular distribution of the radiation for the $\pi$-polarization component and the amplitudes of the axial electron oscillations is established.

A detailed theoretical study of the polarization properties of the electromagnetic radiation emitted by electrons moving through a homogeneous magnetic field has been made by Sokolov and Ternov.[1,2] This radiation, arising from electrons accelerated in high-energy cyclical accelerators, is also important in astrophysics, since the radiation from many objects in the cosmos has the same physical nature as synchrotron radiation. With the construction of high-energy cyclical electron accelerators, it has become possible to conduct experimental studies of the properties of this new form of electromagnetic radiation. The polarization properties of the radiation emitted by electrons has been studied in several experiments,[3-7] but almost all these experiments, except for that of Joos,[7] involved electrons of energy no greater than 250 MeV. Joos's experiment, in which the polarization of radiation emitted by electrons accelerated to an energy of 700 MeV was studied, contains very little experimental data on the intensity of the polarization components. In the present experiment, we made a detailed study of the polarization properties of the radiation emitted by electrons accelerated in the 680-MeV synchrotron of the Physics Institute of the Academy of Sciences.

This synchrotron (of the "racetrack" type) has a vacuum chamber with a special tubular opening whose axis is tangential to the curvilinear segment of the electron orbit. This tubular opening made it possible to observe the radiation emitted by the electrons accelerated in the vacuum chamber of the synchrotron. The visible radiation of the electrons was recorded with the aid of an SKS-1 high-speed camera; the camera could take 500 frames per second. The camera photographed the light spot produced in the focal plane of one of the lenses placed in front of the opening in the synchrotron vacuum chamber. Owing to the properties of the focal plane of the lens, the light spot could be used to determine the angular distribution of the radiation from the radiating object.

We were interested in the angular distribution of the radiation in the vertical plane, since the angular distribution in the horizontal plane is strongly distorted. This distortion is due to the fact that the electron, moving in a circle situated in the horizontal plane radiates tangentially to the plane, and therefore the angular distribution of the radiation emitted from two neighboring points is partially superimposed on one another. In order to separate the $\pi$ and $\sigma$ components of the polarization,[2] the film was exposed to the electron radiation through a Wollaston prism, which gave two images of the focal plane of the lens. Since the spatial separation of the two images produced by the Wollaston prism was small, we used a diaphragm in the shape of a narrow vertical slit (4 mm wide) in the focal plane of the lens in order to avoid the superposition of the images. The optical system was chosen in such a way so that the entire vertical spread of the radiation cone passed through the system without being diaphragmed.

A time marker (neon lamp) triggered by a ZG-10 acoustic-frequency generator was used to record on the film the time after the beginning of the acceleration. Glass filters were used for the separation of definite spectral intervals of radiation.

To recalculate the density of the image of the angular distribution on the film into radiation intensity, we made use of a characteristic curve. To construct the characteristic curve of the camera, a graduated optical wedge illuminated by the light from the accelerated electrons was photographed by the camera. All pictures were taken with film of the same type and these films were developed simultaneously in the same solution. Photometric readings of the obtained films were carried out on an MF-4 microphotometer. Photometric measurements of the images of both polarization components were performed in a direction corresponding to the vertical. These measurements made it possible to obtain the angular distribution of the intensity for both polarization components for the entire acceleration cycle, i.e., for all energies of the electrons.

Typical examples of the angular-distributions of the polarization component intensities for different energies of the accelerated electrons are shown in Fig. 1. It is seen from the curves that there is good agreement between experiment and theory, especially for the more intense $\sigma$ component. More complete results of the comparison between experiment and theory are listed in the table, where the values of the half-width for both polarization components averaged over the acceleration cycle are compared. This averaging makes sense, since theoretical calculations show that the half-width of monochromatic radiation changes very little as the electron energy changes.

The data show satisfactory agreement between theory and experiment. There is, however, a difference between the experimental and the theoretically calculated angular distributions of the radiation intensity, especially for the $\pi$ polarization component. A characteristic feature of the angular distribution of the radiation for the $\pi$ component is that in the direction of the instantaneous velocity (tangential to the electron orbit) no radiation should be observed. However, at the beginning of the acceleration (at small electron energies), this minimum is not observed at all. As the electron energy is increased, this minimum appears and becomes deeper, but never dips to zero. Towards the end of the acceleration cycle, the intensity at the minimum again increases.

For a quantitative estimate of the value of the minimum, we measured the ratio of the intensity

| λ, Å | E, MeV | Mean value of the half-width of angular distribution for $\sigma$ component | | Mean value of the half-width of angular distribution for $\pi$ component | |
|---|---|---|---|---|---|
| | | theory | experiment | theory | experiment |
| 4360 | 250—500 | 24′ | 22′±1′ | 31.5′ | 29.5′±1′ |
| 5780 | 250—500 | 24′ | 22′±0.5′ | 34′ | 30.3′±0.3′ |

at the minimum to the intensity at the maximum of the $\pi$ polarization component over the entire acceleration cycle for three different films. The results of these measurements are shown in Fig. 2. The fact that the intensity never drops to zero can be explained by the presence of axial oscillations of the electrons, which is confirmed by the agreement between the experimental points and the curve representing the variation of the rms amplitude ($\sigma_a$) of the axial oscillations (in Fig. 2, this curve is shown as a solid line). The curve of the variation in $\sigma_a$ was obtained for the given case by a method described previously.[8] The experimental values of the ratio of the minimum to the maximum were equated to the rms amplitude of the axial oscillations at the time t = 0.4 sec. For the maximum value of the intensity of the $\pi$ polarization component, we took the mean value of the two maxima in the angular distribution

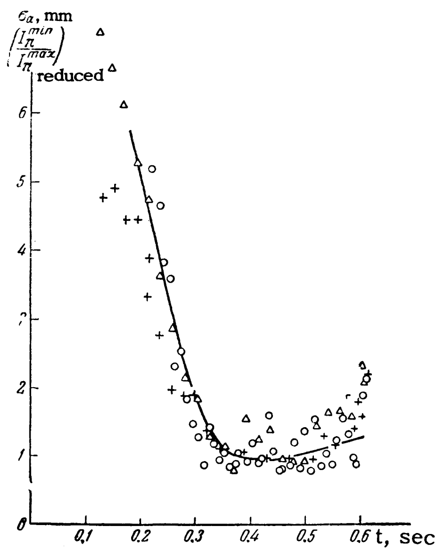


FIG. 2. Ratio of the intensities at the maximum and minimum for the $\pi$ polarization component of the electron radiation. The three different types of points represent the experimental data for three different films. The solid curve represents the variation of the rms amplitude ($\sigma_a$) of the vertical oscillations.

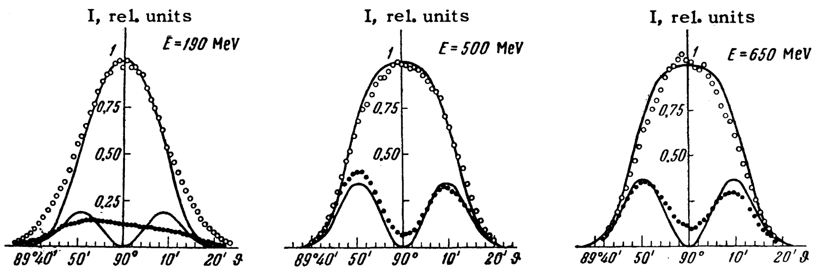


FIG. 1. Angular distribution of the intensity of the $\sigma$ and $\pi$ components at different times of the electron acceleration cycle for λ = 4360 Å. The angle $\theta$ is measured relative to the direction of the synchrotron magnetic field. The points represent the experimental data, the solid lines represent the theoretical curves calculated from Sokolov's formulas.[2]

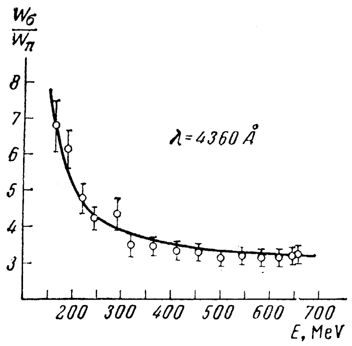


FIG. 3. Ratio of the radiation power for $\sigma$ and $\pi$ components at different electron energies.

which could be distinguished from one another. Here, for all films and frames, regardless of the rotation of the Wollaston prism, it turned out that the maximum radiation of the $\pi$ component of the polarization corresponding to the direction of radiation at an angle $\vartheta < 90°$ (above the orbital plane) had a greater value than the maximum of the radiation corresponding to an angle $\vartheta > 90°$.

It should be noted that the inequality of the maxima of the $\pi$ component intensity was also observed in synchrotron radiation from other accelerators.[4,7] This inequality of the $\pi$ component maxima for synchrotron radiation could be due, in particular, to the nonsinusoidal character of the axial oscillations of the electrons in the synchrotron.

We measured the areas embraced by the angular distribution curves for the radiation intensity in both polarization components of the synchrotron radiation and calculated their ratio for each frame of the film for one cycle of electron acceleration. From these data, we constructed curves characterizing the ratio of the radiative power of the $\sigma$ and $\pi$ components as a function of the electron energy for two different wavelengths of light emitted by the electrons. One of these curves is shown in Fig. 3. In the figure, the solid line represents the theoretical calculations based on Sokolov's formula[2] for the ratio of the radiative power of the polarization components. Within the limits of experimental error, it can be stated that there is good agreement between the experimental and theoretical data.

The measurements showed that the angular distribution and polarization properties of the radiation described in [1,2] agree with the experimentally observed properties up to electron energies of 680 MeV.

The authors consider it their duty to express their gratitude to Professor V. A. Petukhov and V. E. Pisarev for their great assistance in this work.

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Translated by E. Marquit
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