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CHANNELING OF POSITRONS OF 1 GeV ENERGY

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Submitted 30 June 1972
ZhETF Pis. Red. 16, No. 3, 162 - 164 (5 August 1972)

The channeling of positrons of ∿28 MeV energy in a silicon crystal along the [110] axis was observed by Walker [1]. We show in the present paper that the effect of channeling of positrons in a crystal exists also at 1 GeV. The channeling of positrons at high energies was never observed before, owing to the difficulty of generating high-energy positron beams with small divergences [2, 3].

In our experiment a beam of positrons with energy 1 GeV and divergence $\leq 2 \times 10^{-4}$ rad was directed on a single-crysjal silicon target mounted in a goniometer. The goniometer has made it possible to rotate the crystal in the vacuum chamber of the accelerator about all three axis, with a reading accuracy 5×10^{-5} rad. The silicon crystal was in the form of a plate 0.64 mm. The normal to the plane of the plate made an angle ∿1° with the [110] axis. The crystal was oriented relative to the beam by a method analogous to that described in [4] in such a way that the [110] crystal axis was directed along the beam axis, and the [001] axis was oriented along the goniometer axis that was perpendicular to the beam direction.

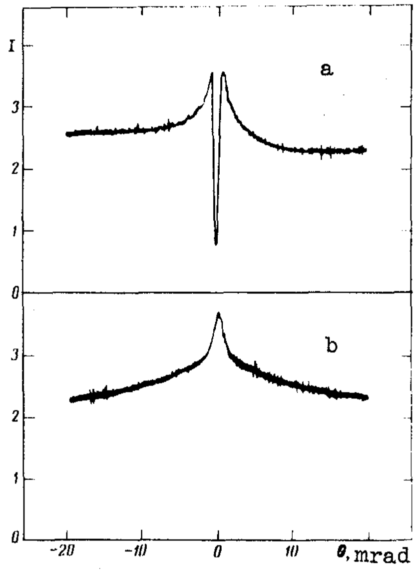

Fig. 1. Bremsstrahlung energy flux vs. angle between the direction of the beam and the silicon [110] crystal axis: a - positrons, b - electrons.

After it interacted with the crystal, the positron beam was reflected with a magnet. The photon beam was registered with a Gauss-quantometer [5] placed behind the crystal. The quantometer registered the energy flux of the bremsstrahlung γ quanta in the direction of the primary positrons, within a solid angle $4\pi \times 10^{-4}$ sr. The results of the measurements performed on the positron beam are shown in Fig. 1a. Figure 1b shows, for comparison, a curve obtained with an electron beam having parameters identical with those of the positron beam. The abscissas are the angles of rotation of the crystal about the [001] axis in milliradians, and the ordinates are the quantum-meter currents in relative units, proportional to the γ-quantum energy flux. It is seen from Fig. 1a that when the positron beam makes an angle smaller than a certain critical value with the crystal axis, the flux of the γ quantum energy decreases sharply.

Figure 2 shows the spectra of the positrons incident on the crystal (1), scattered by the crystal when the beam angle is parallel to the [110] axis of the crystal (2), and scattered by the crystal when the angle between the beam and the [110] axis is 30 mrad. The positron spectra were measured with a magnetic spectrometer subtending 10^{-2} rad in a horizontal direction and 10^{-3} rad in a vertical direction. The abscissas of the plot represent the positron energy E in MeV, and the ordinates the positron current I in relative units, with energies in the interval (E, E + 0.01E). The current measurement error did not exceed 5%.

When the positron was directed along the [110] axis of the silicon crystal, the spectrum of the scattered positrons was narrower than in the case when the angle between the beam and the [110] axis was 30 mrad, and was closer to the spectrum of the positrons incident on the crystal. The total number of scattered positrons within the angle subtended by the spectrometer increases when the positron beam is directed along the crystal axis, i.e., the scattering angles of the positrons moving along the crystal axis are smaller.

The angular width of the minimum bremsstrahlung energy flux at half the depth (Fig. 1), equal to 6×10^{-4} rad, agrees within the limits of the errors due to the primary divergence of the beam with the value of the critical channeling angle obtained from Linhard's formula [6].

Thus, the results of our investigation point to the existence of positron channeling in a crystal at a positron energy 1 GeV.

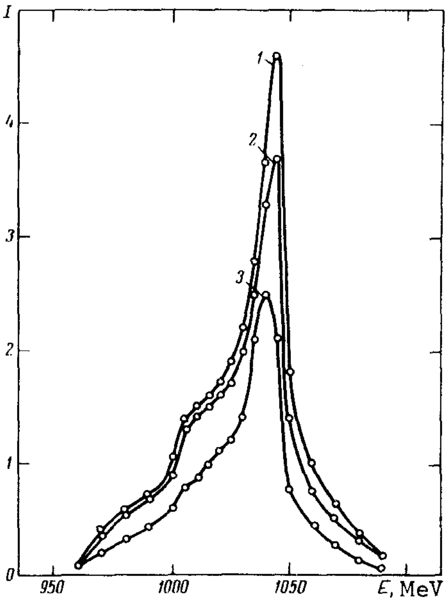

Fig. 2. Spectra of the positrons incident on the crystal (1), scattered by the silicon crystal when the beam is directed along the [110] axis (2), and scattered by the silicon crystal when the angle between the beam and the [110] axis is 30 mrad.

For a detailed study of the features of the channeling of high-energy positrons in a crystal additional work must be done on the shaping of positron beams with a divergence much smaller than the critical channeling angle.

At the existing beam parameters, the effective channeling of relativistic positrons in the crystal can be used to orient the crystal relative to a beam, for the detection of flaws in thick crystals, etc.

It is our pleasant duty to thank the accelerator crew headed by V.M. Kobeskii for faultless operation of the accelerator, and V.I. Popenko for help with shaping the beams.

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HIGH-FREQUENCY HEATING OF A PLASMA UNDER CONDITIONS OF ION-ION HYBRID RESONANCE

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Submitted 3 July 1972
ZhETF Pis. Red. 16, No. 3, 165 - 167 (5 August 1972)

One of the main problems in controlled thermonuclear fusion is the development of methods of plasma heating in closed magnetic traps. An important role in its solution can be played by high-frequency heating methods. We have reported in [1] that the ions of a dense plasma can be heated with high efficiency in a toroidal trap by axially-asymmetrical ion-cyclotron waves which are damped in the region of an attenuated magnetic field (by a "magnetic beach").

In the present communication we report experimental results of heating of a plasma consisting of a mixture of hydrogen and deuterium ions in the "Omega" apparatus, with a toroidal magnetic field that is uniform along the axis under conditions of ion-ion hybrid resonance.

As is well known, an opacity region, in which the wave amplitude decreases exponentially, usually exists between the boundary of a radially inhomogeneous plasma and the resonance region [2]. For the waves to penetrate into the resonance region it is necessary that the dimensions of the opacity region be smaller than the length of the exciting wave. As shown by a theoretical analysis, in the general case the values of the plasma density corresponding to the zeroes (0) and poles (∞) of the function $k^2(r)$, i.e., to the points of reflection and absorption, are quantities of the same order of magnitude. Consequently, the penetration of a wave into the central region of the plasma, where it is desirable to produce resonance conditions, may be very difficult because of the presence of reflection points in the region of plasma density values that are smaller than on the axis ($n_0(r) < n_\infty$, $n_0 \sim n_\infty$). However, if the condition $B \ll 1$ ($B > 0$ are satisfied[1]), the values of n_0 and n_∞ turn out to be essentially different

$$X_\infty = -\frac{2C}{B}, \quad X_0^{\pm} = \frac{C}{\sqrt{-A}} \text{ where } X(r) \quad \frac{\omega_{pi}^2(r)}{\omega_{ci}^2},$$

$$C \equiv 1 - \frac{k_\parallel^2}{k^2}, \quad B \equiv -\frac{2\Omega_1^2}{NZ}[N(1-\Omega_2^2) \quad 2(1-\Omega_1^2)],$$

$$A \equiv -\frac{1}{N^2Z}[\Omega_1(1-\Omega_2^2)N^2 - 2\Omega_1^2(\Omega_1\Omega_2 - 1)N + \Omega_1^2(1-\Omega_1^2)],$$

$$Z \equiv (1-\Omega_1^2)(1-\Omega_2^2); \quad \Omega_{1,2} = \frac{\omega_{ci\,1,2}}{\omega}, \quad N = \frac{n_1}{n_2}$$

n is the ion concentration (the subscripts 1 and 2 pertain to deuterons and protons, respectively). As follows from (1), the reflection point shifts into the region of low plasma densities, where $\bar{\lambda}_\perp \equiv 1/k_\perp(r) > L_\perp$ ($L_\perp$ is the dimension of the opacity region). In this case the wave energy can pass from the exciting device into the propagation region where $k_\perp^2 > 0$.

The high-frequency power was fed into the plasma with the aid of exciting devices that produce in the plasma a wavelength $\lambda_\parallel \sim 130$ cm, analogous to those

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[1] The condition $B > 0$ ensures transparency of the plasma in the region $n(r) < n_\infty$.