The Growth of Interaction Cross-Section of 4.3 GeV Electrons in Excited Crystals

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January 8, 2022

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Abstract

The microscopic properties of the interactions of relativistic electrons were observed to alter when macro-conditions, such as the crystal vacuum, were changed. A qualitative explanation of the phenomenon is given.
Introduction

The present paper is a continuation of earlier experimental works on the interaction of relativistic electrons with excited crystal vacuum as the physical medium. The first observations of the effect were carried out in 1976, delivered at a conference [1] and reported in papers [2, 3, 4].

Briefly, the observed phenomenon consists essentially in the fact that beginning from some threshold intensity of the electron beam passing through a single crystal, the radiation increases with the beam intensity. The results of measurements point out that the emitted intense radiation is due to the interaction of bunch as a whole with the crystal. This radiation is produced on the boundary of crystal (like the transition radiation) that is excited by the same beam, and below we shall name that as the vacuum radiation. It is basically low energy radiation [4] and proved to be by many times more intense than the channeling radiation under the same condition [3].

In the present paper we provide new more explicit experimental data in support of the electron beam intensity effect. The measurements have been taken on the internal electron beam of the Yerevan Synchrotron with the same experimental setup [4, 5]. Below we give measurement data obtained using two different techniques with better monitoring of electron and gamma-beam intensities:

1 Experimental results

1.1 Technique one

Data measured by means of ionization chambers, where the chamber was placed at the distance of 20 m from the diamond crystal downstream the beam-line, and the beam was collimated (by 3×3 mm² aperture) at 10 m from the same crystal. The γ−beam was cleaned of charged particles and passed parallel to the chamber electrodes (in the air gap of 1.5 cm). The electrons (positrons) that converted on air from gamma-quanta of energies up to the edge of bremsstrahlung spectrum contributed to the ionization current. Despite high background from higher energy photons, the contribution of low energy photons from the oriented crystal proved to be predominant. The data obtained with the help of ionization chamber \(N_i\) were normalized to those of quantameter \(N_q\), which was gamma-beam intensity monitor. The dependence of ratio \(N_i/N_q\) on the angle \(\psi\) of electron incidence on (110) planes is given in Table 1. Two rightmost columns correspond to the case, when 100 µm thick aluminum converter was installed in front of the ionization chamber. Though the ratio \(N_i/N_q\) grows both at the disoriented and oriented \(\psi = 0\) crystals when the electron intensity is increased, in the latter case the effect is more pronounced. It is worthwhile to note that though the effect appears to be small, in reality it is rather strong since, as was mentioned above, all photons of the bremsstrahlung spectrum, and not only the low energy ones, make contribution to the current of ionization chamber. The ionization chambers have the advantage that in contrast to the photomultiplier tube base detectors, it is an integral action instrument that like the quantameters may be operated at high particle fluxes.

| Intensity, γ−quanta/sec | 1000 | 2500 | 1000 | 3000 |
|-------------------------|------|------|------|------|
| Chamber converter       | Air  | Aluminum foil + Air |
| Disoriented crystal     | 1.23 | 1.29 | 1.39 | 1.69 |
| \(\psi = 0\)            | 1.20 | 1.60 | 2.11 | 3.16 |
1.2 Technique two

The radiation losses of electrons were also detected by the missing energy of electrons. Here the synchrotron *per se* served as a spectrometer of missing energy. In such a case the detection is made within a narrow energy range and the intensity effect is strongly manifested. An increase in instantaneous beam intensity (i.e., the beam density) is achieved by inducing a faster beam dump. The electrons that lose some threshold energy in the crystal may be thrown out by the beam dump on the walls of the synchrotron vacuum chamber primarily near the target crystal. The produced showers will be partly detected with a scintillation counter placed near the crystal. The detector had a voltage lower than nominal to have a higher counting rate capability. The relative monitoring of electrons interacting with the crystal has been made with the quantameter. The measurement data are given in Tables 2,3 for two orientations of the crystal. There is no need for giving the orientation dependence on the whole as was made in [4]. A sharp increase in the counting rate with electron intensity (∼3 times) is seen in Table 2 for crystal orientation $\psi = 0$. A sharp increase is observed even at the orientation $\psi = 0.46$ mrad. The same is seen in Table 3 with data taken using another scintillation counter with the gamma-converter placed in the experimental hall at the distance of 30 m from the diamond crystal, the gamma-beam being collimated by $6.7 \times 6.7 \text{ mm}^2$ aperture. As the energy acceptance of detector here is wider than in Table 2, the integral effect is naturally less pronounced. The produced results explicitly confirm the presence of electron beam intensity effect showing up as an increase in the radiation cross-section of 4.3 GeV in diamond single crystal.

| Beam dump       | Slow dump | Faster dump |
|-----------------|-----------|-------------|
| Disoriented crystal | 284 ± 9     | 6.7·10^3    |
| Oriented crystal, $\psi = 0.46$ mrad. | 1.2·10^3 | 6.6·10^3 |
| Orientation $\psi = 0$ | 5.2·10^3 | 10^6 |

| Beam dump       | Slow dump | Faster dump |
|-----------------|-----------|-------------|
| Disoriented crystal | (0.58 ± 0.02)·10^4 | 1.7·10^3 |
| Oriented crystal, $\psi = 0.34$ mrad. | 1.8·10^4 | 5.26·10^3 |
| Orientation $\psi = 0$ | 3.9·10^4 | 17.5·10^3 |

2 Conclusion

One can interpret this phenomenon as a result of electron interactions with a nonlinear medium such as an excited crystal. It may be qualitatively explained as follows: the first relativistic electrons of a bunch travelling through a crystal knock out electrons of atomic shells, as a result of which the electromagnetic vacuum near these atoms is excited. In case of high intensity electron beam the correlations of excitations in this non-equilibrium process are strengthened and grow macroscopic in the range of characteristic frequencies $\omega_{ex}$. This may mean a spontaneous symmetry breaking of the vacuum in this case of electromagnetic vacuum. As a result, the permittivity of medium may be $\varepsilon < 1$ in the range $\omega_{ex} < \omega < \omega_{ex}\gamma$ (where $\gamma$ is the Lorentz-factor of relativistic electrons). When the other relativistic electrons of the bunch enter the medium with changed structure of that kind, they will emit photons in the mentioned frequency range due to virtually polarized atoms similar to the transition radiation, the frequencies of which are considerably lower. For example, the energy of $K_\alpha$ transition in carbon (the diamond) is
283 eV, but that of the plasma frequency is $\sim 20$ eV. The frequencies $\omega_{ex}$ and $\omega$ for substances with larger atomic numbers $Z$ must be still higher. Therewithal the intensity of radiation will be determined by the degree of vacuum excitation. The faster-than-quadratic increase of radiation cross-section in Table 2 is, apparently, due to the non-equilibrium phase transition in the excited vacuum. The periodicity of crystal structure and its orientation influence in such conditions both the radiation spectra and angular distributions (anomalous wide one $\text{[9]}$) of gamma-quanta, as the density of substance is increased in the directions of crystal planes and axes. In our experiments the intense vacuum radiation has been really observed in the range of several MeV $\text{[4]}$. Although the radiation yields decrease at higher energy of photons, the influence of the medium excitation is appreciable up to the end of the bremsstrahlung spectrum $\text{[9]}$. All these facts do not contradict the aforementioned interpretation. The measurements of radiation spectra in terms of electron beam intensity effect and the theoretical treatment of radiation mechanism are, however, of current interest. It is noteworthy that the subject of this work transgresses the bounds of purely radiative processes, as they happen in strongly non-equilibrium medium, that takes place, for example, in relativistic heavy ion collisions (the citing of Refs $\text{[6, 7]}$ here was not accidental). In this sense the subjects touched upon in the paper are of interest for many fields of physics. Not to go into details, we should only like to mention that this vacuum radiation was used since 1976 for finding the planes and axes of crystals. It is obvious that this vacuum radiation may find wide application:

1. As a source of regenerated positrons in future electron-positron linear colliders;
2. As a source of monochromatic gamma-quanta in the range of 5 - 50 keV in small electron accelerators with energies 20 - 100 MeV.
3. For preparation of an active medium for potential gamma-lasers.

Acknowledgments

In conclusion the author thanks Avakian R., Berman B. and Ter-Michaelyan M. for discussions.
Table Captions

Table 1. Normalized integrated ionization currents $N_i/N_q$ versus the electron beam intensity with two different converters of gamma-quanta at two different orientations of 72 $\mu$m thick diamond crystals. The statistical errors were neglected.

Table 2. Counting rates of the detector for some orientations of crystal for different intensities of electron beam. The diamond crystal was 100 $\mu$m thick.

Table 3. Counting rates of the detector placed in the experimental hall for some orientations of 100 $\mu$m thick crystal for different intensities of electron beam.

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