INTERFERENCE OF SYNCHROTRON RADIATION PHOTONS FROM A SINGLE ELECTRON

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An interference experiment is carried out with statistically independent synchrotron radiation photons from a single electron in a storage ring. It is shown that for an intensity which practically excludes the simultaneous presence of two photons in the interferometer, the radiation of one or more electrons produces an interference pattern whose quality does not depend appreciably on the number of radiators. In the opinion of the authors the results of the experiment are convincing proof of the validity of the quantum-mechanical principle of superposition for super-low radiation fluxes.

1. INTRODUCTION

ONE of the basic postulates of quantum mechanics is the principle of superposition. This appears most clearly in the interference of light fluxes. This explains the interest expressed at various times by a number of investigators[1-4] in study of the interference of super-weak fluxes of statistically independent photons, since the preservation of the nature of the interference pattern with decrease in intensity of the light fluxes would be convincing experimental confirmation of the principle of superposition.

However, the studies mentioned above are not free from certain deficiencies which appear to us to be important: 1) lack of detection of individual photons[1]; 2) the source of photons in the experiments was an ensemble of radiators (electrons[3] or atoms in a low-pressure discharge tube[2,4]), which in principle did not exclude the possibility of interaction between them and the influence of this interaction on the nature of the interference pattern produced. In this connection an experiment in which the photon source would be a single emitter and the detector would permit recording single photons would completely satisfy the requirements necessary for experimental verification of the principle of superposition. It appears to us that synchrotron radiation of a single electron in a storage ring, which consists of statistically independent photons, is the most suitable source for solution of this problem. In our earlier study[3] the minimum number of electrons whose radiation was detected in the interference pattern was ten, and in addition the detection system did not permit reliable identification of individual photons. We have now carried out an experiment with improved apparatus, with which statistically independent single photons emitted by a single electron have been reliably recorded in the interference pattern.

2. EXPERIMENTAL ARRANGEMENT

The experimental arrangement is similar to that described previously[3] and is shown in Fig. 1. The radiation detector was a photomultiplier in the single-photon counting regime[5], together with mirror or scanning probes whose construction is shown schematically in the same figure. The design of the mirror probe was intended for simultaneous measurement of the radiation intensity at the minima and the maxima of the interference pattern projected on it. However, since we did not have available two photomultipliers with identical quantum characteristics, the measurements were made with a single photomultiplier by displacement of the probe relative to the interference pattern. In a portion of the experiments a scanning probe was used. The photomultiplier pulses were amplified with a UIS-2 amplifier and counted by a PP-9 scaling system.

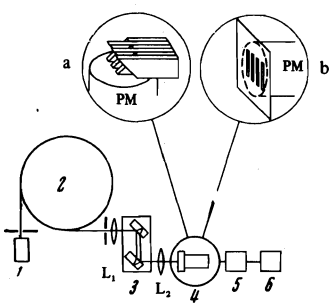

FIG. 1. Diagram of the interference experiment. 1—counter for number of electrons in the orbit; 2—storage ring; 3—Jamin interferometer; L_1 and L_2—lenses; 4—interference probe (a—mirror, b—scanning) and radiation detector; 5—amplifier; 6—scaling circuit.

3. METHOD OF MEASUREMENT

Before beginning the measurements, we visually adjusted the probe together with the detector, with a large number of radiating electrons. The adjustment consisted of matching the maxima (minima) of the interference pattern, produced by means of a Jamin interferometer under achromatic observation conditions, with the reflecting surfaces of plates with even (odd) numbers—in the case of the mirror probe—or with the slits—in the case of the scanning probe. After the measurements a visual check was made of the location of the bands on the plates (slits).

In carrying out the measurements, the magnitude and stability of the photomultiplier noise during a run and during the entire experiment were of great importance. In this connection, measures were taken to avoid illumination of the photomultiplier cathode by intense fluxes of synchrotron radiation and also γ rays arising on injection of electrons into the storage ring. The photomultiplier noise level was measured before and after each run and its value during the course of the experiment amounted to ~160 counts/sec.

The number of radiating electrons in the storage ring orbit was continuously measured by a special electron counter. After the number of electrons in the orbit was reduced to 20, a gate was opened in front of the probe and the number of counts in the lifetime of each given number of electrons was measured, down to one, inclusive. After the disappearance of the last electron the noise counting rate was again measured. Before the beginning of the next run, the probe and detector were shifted across the interference pattern by the extent of the interference maximum, so that in neighboring runs the radiation intensities associated with the maxima and minima of the pattern were measured. The amount of displacement was controlled with an accuracy of 0.05 mm for a width of the interference maximum of 2 mm.

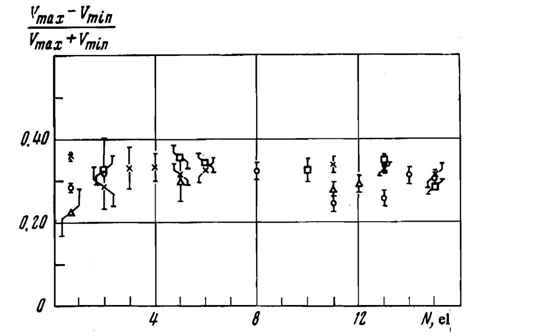

FIG. 4. Visibility of the interference pattern from the radiation of various numbers of electrons, calculated for neighboring runs.

4. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 2 shows the experimental results for the case of one and two radiating electrons. It is evident that the counting rate at the maxima of the interference pattern exceeds the counting rate at the minima. Figure 3 shows the results of averaging the counts over the runs made for the maxima and minima. Here the number of electrons varied from 16 to unity. Since the lifetime of the N-electron state in each run is statistical, all averagings were carried out with allowance for the unequal accuracies of the measurements. In Fig. 4 we have shown the values of the ratios

$$(V_{max} - V_{min}) \,/\, (V_{max} + V_{min}),$$

calculated for neighboring runs.

As can be seen from Fig. 2, the average counting rate associated with the entire interference pattern for presence in the storage ring orbit of one electron was 60 counts/sec. When the experimental geometry, interferometer light transmission, and average quantum efficiency of the detector photocathode in the optical region are taken into account, this value is in good agreement with the intensity of synchrotron radiation of a single electron calculated theoretically in the one-photon approximation[6], 1.3×10^3 photons/sec in the interference pattern (1.3×10^5 photons/sec at the entrance to the interferometer), from which it can be concluded that the main contribution to formation of the interference pattern is from single electrons. Here the average time interval between the photons was 10^{-5} sec, which is considerably greater than the 10^{-9} sec time of passage of the photons through the interferometer.

From the data obtained we can draw the following conclusions.

1. Statistically independent photons of synchrotron radiation of one electron in the storage ring produce i an interference pattern.

2. The nature of the interference pattern does not change appreciably as the number of radiating electrons is varied from 16 to unity.

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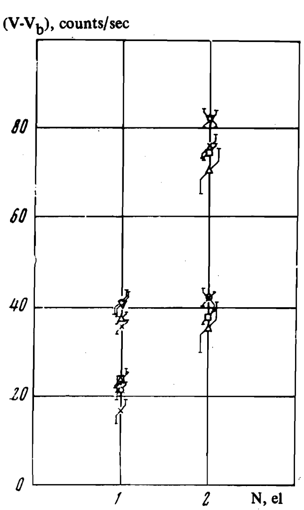

FIG. 2

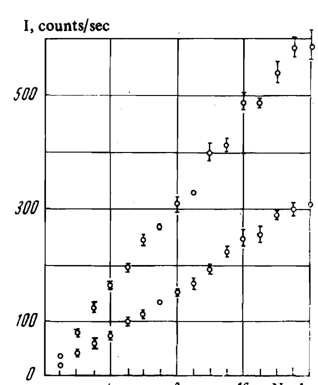

FIG. 3

FIG. 2. Counting rates at the interference minima and mixima of the radiation from one and two electrons.

FIG. 3. Counting rates at the interference maxima and minima of the radiation from electrons ($1 \leqslant N \leqslant 16$).

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