MEETINGS AND CONFERENCES

Scientific session of the Division of General Physics and Astronomy, Academy of Sciences of the USSR (29–30 November 1978)

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A joint scientific session of the Division of General Physics and Astronomy and the Division of Nuclear Physics of the Academy of Sciences of the USSR was held on November 29 and 30, 1978, at the conference hall of the P. N. Lebedev Physics Institute. The following papers were delivered:

1. *D. F. Alferov, Yu. A. Bashmakov, K. A. Belovintsev, E. G. Bessonov, and P. A. Cherenkov,* Sources of undulator radiation (Theory, Experiment, Applications).

2. *Yu. M. Aleksandrov, A. K. Krivospitskiĭ, and M. N. Yakimenko,* X-ray lithography in synchrotron radiation beams.

3. *Yu. M. Kagan,* Coherent excitation of isomeric nuclear states in a crystal by synchrotron radiation.

4. *A. N. Artem'ev, V. A. Kabannik, Yu. N. Kazakov, G. N. Kulipanov, E. A. Meleshko, V. V. Sklyarevskiĭ, A. N. Skrinskiĭ, E. P. Stepanov, V. B. Khlestov, and A. I. Chechin,* An experiment in excitation of a Mössbauer level of ^{57}Fe with synchrotron radiation.

5. *M. A. Mokul'skiĭ,* Use of synchrotron radiation for x-ray diffraction study of biopolymers.

6. *A. A. Vazina,* Investigation of the dynamics of structural changes in biomolecular systems by methods of high-speed diffractometry with synchrotron radiation.

7. *V. V. Mikhaĭlin,* Synchrotron radiation in solid-state spectroscopy.

8. *S. P. Kapitsa,* Present and future sources of synchrotron radiation.

Below we publish brief contents of five of the papers.

D. F. Alferov, Yu. A. Bashmakov, K. A. Belovintsev, E. G. Bessonov, and P. A. Cherenkov. *Sources of undulator radiation (Theory, Experiment, Applications).* Interest in the study of ultrarelativistic electrons in undulators has increased considerably in recent years with the widespread use of synchrotron radiation (SR) sources in scientific research practice and with progress in work to improve the characteristics of the radiation. Higher directivity, spectral intensity, and degrees of polarization, the type of which can be controlled operationally, distinguish undulator radiation (UR) favorably from SR.

The idea of the undulator was advanced by V. L. Ginzburg in 1947.[1] It was developed further and put to work in practice by Motz and other authors.[2]

Moving along the axis of the undulator, an ultrarelativistic charged particle describes periodic oscillations about a certain uniformly moving center. This motion can be realized in static magnetic fields, in the field of an electromagnetic wave, in a crystal, etc. Motion of charged particles in an undulator is accompanied by electromagnetic radiation at frequencies determined by the Doppler effect:

$$\omega_k=\frac{k\Omega}{1-\beta_{\parallel}\cos\theta}\approx\frac{2\Omega\gamma^2k}{1+(\beta_{\perp}\gamma)^2+(\theta\gamma)^2}\quad(\theta\ll1,\ \gamma\gg1),\qquad(1)$$

where $\gamma=\varepsilon/mc^2$, ε is the energy of the particle, m is its rest mass, $\Omega=2\pi\beta_{\parallel}c/\lambda_0$ is the frequency of the particle's oscillations, λ_0 is their period, θ is the angle between the longitudinal component $\beta_{\parallel}c$ of the particle's velocity and the direction in which the radiation propagates, and k is the harmonic number of the radiation.

A distinctive property of UR is the single-valued dependence of the radiation's frequency at a given harmonic on the observing direction (1)—the spatial monochromaticity of the radiation. The relative width of the spectral band at frequency ω_k is determined by the undulator's length $L=K\lambda_0$ and equals $\Delta\omega/\omega_k\approx1/kK$.

The radiation intensity in a beam of randomly distributed particles is proportional to the number N of particles (spontaneous incoherent UR). A particle beam that has been shaped into a series of bunches whose characteristic dimension is of the order of the length of the radiated wave will emit coherent UR with an intensity proportional to N^2. Efficient amplification of an electromagnetic wave by a beam of charged particles in an undulator (induced UR) is possible under certain conditions.

The theory of spontaneous incoherent, coherent, and induced UR is set forth in Refs. 1–11 and the literature cited therein.

The characteristics of the radiation depend strongly on the relation between the maximum angle $\beta_{\perp}$ through which the particle velocity vector has been rotated in the undulator and the angle $1/\gamma$.

1. If $\beta_{\perp}\gamma\ll1$ (dipole approximation), most of the radiation energy is concentrated near the undulator axis in a range of angles ~$1/\gamma$. In the case of harmonic

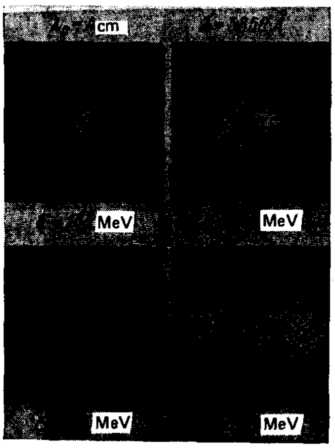

FIG. 1.

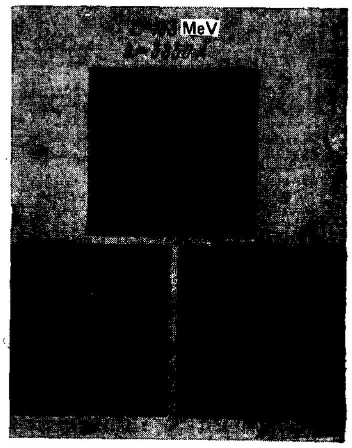

FIG. 2.

particle motion, only the first harmonic is emitted and its spectrum drops off sharply at frequencies $\omega \gtrsim 2\Omega\gamma^2$.[10,11]

2. In the case $\beta_\perp\gamma \approx 1$, the amplitude of the oscillations increases and the longitudinal velocity of the particle decreases, with the result that the frequency of the radiation in a given direction is lowered. The fraction of radiation at higher harmonics increases with increasing field. An important characteristic of the undulator is the existence of an optimum field value at which the intensity of the radiation at the first harmonic along the undulator axis is highest.[3] At near-optimum and smaller fields, most of the radiation energy goes into the first harmonic. In this case the half-width of the UR spectrum is much smaller than that of the SR spectrum.

3. In the limiting case of strong fields in the undulator ($\beta_\perp\gamma \gg 1$) the total intensity and hardness of the radiation increase. The shape of the UR spectrum approaches that of the SR spectrum, but the spectral-angle and polarization characteristics differ from the corresponding SR characteristics.[3,4] Thus, the interval between neighboring UR harmonics in a given direction is much larger than it is in the SR spectrum.

The polarization characteristics of undulator radiation depend on the shape of the particle paths in the undulator.[3,4] If the particle moves along a sinusoidal trajectory, the radiation in the direction along the undulator axis consists of a set of odd harmonics and is completely linearly polarized at a given frequency irrespective of the magnitude of the field in the undulator. In the case of motion along a helical line, only the first harmonic, which is circularly polarized, is radiated along the undulator axis. In a spiral undulator with the optimum field, the radiation is characterized by a high degree of circular polarization in the angle range $\theta \sim 1/2\gamma^4$.

Intense UR can be obtained by placing undulators in linear gaps of synchrotrons and storage rings. The first experiments to study UR from the orbit of a ring accelerator were made recently[12,13] on the "Pakhra" synchrotron of the Physics Institute of the Academy of Sciences (FIAN) and later[14] on the "Sirius" synchrotron of the Tomsk Polytechnic Institute (TPI). The undulator installed in the linear gap of the "Pakhra" synchrotron has 20 periodicity elements. The length of each element is $\lambda_0 = 4$ cm. Under the conditions of the experiment, the transverse magnetic field of the undulator was varied sinusoidally along the beam axis with an amplitude $H_m \sim 360$ Oe ($\beta_\perp\gamma \sim 0.13$).

UR of practically monoenergetic electrons was registered with photographic plates in the wavelength range 2000–5500 Å.

The possibility of threshold measurement of charged-particle energies that was pointed out in Ref. 10 was confirmed in these experiments.

Optical-filter study of features of the angular radiation-intensity distribution confirmed the spatial monochromaticity property of UR. Figure 1 presents photographs of the radiation of electrons with various energies at wavelength $\lambda = 3850$ Å, $\Delta\lambda/\lambda \approx 4.4\%$. The angle at which the radiation propagates at this wavelength increases with increasing electron energy. The intensity of the radiation in the plane of oscillation of the particles decreases noticeably at angles $\theta \sim 1/\gamma$ ($E \sim 163$ MeV). The width of the angular distribution decreases significantly as the observing angle increases.

The dependence of the radiation frequency on the observing direction at a fixed electron energy is especially clearly illustrated by color photographs obtained in this experiment.

Figure 2 shows the distributions of the radiation polarized in the oscillation plane of the electrons (the σ component) and in the perpendicular plane (π component). The variations in the distributions of these components with azimuth differ significantly and agree with theoretical concepts.

The measurements made of the radiation spectra also indicated good agreement between the experimental data and theory.[13] We note that the UR flux density was several times higher than the corresponding SR flux density in these experiments.

Owing to its unique properties, UR may have broad applications in physical research.[4] For example, use of undulators to obtain strong fluxes of polarized monochromatic high-energy photons from collidingbeam apparatus and from ultrahigh-energy electron beams in the largest proton synchrotrons appears promising. The properties of UR open fundamentally new opportunities for the use of optical systems to record parameters of proton, antiproton, and other particle beams. The development of induced-UR sources is of great interest, since they would enable us to produce strong coherent electromagnetic radiation in a broad range of the spectrum down to λ ~ 1000 Å with operationally controllable frequencies. Generation of coherent UR in a harder region of the spectrum is also possible.[5]

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