Technical Physics, Vol. 46, No. 12, 2001, pp. 1579–1581. Translated from Zhurnal Tekhnicheskoĭ Fiziki, Vol. 71, No. 12, 2001, pp. 92–94.

Formation of an External Source by a Hard Radiation Pulse in an Electrodynamic Problem

F. F. Valiev

St. Petersburg State University, Universitetskiĭ pr. 2, St. Petersburg, 198504 Russia

e-mail: valiev@snoopy.phys.spbu.ru

Received November 3, 2000; in final form, March 2, 2001

Abstract—A method is proposed for calculating an external source that forms when hard radiation is absorbed by matter. The relevant electrodynamic problem is solved by numerical modeling. It is shown that the current density vector can be localized in space and time. *© 2001 MAIK "Nauka/Interperiodica".*

The investigation of electromagnetic waves accompanying the absorption of gamma-ray photons by matter implies a calculation of the macroscopic current density vector, i.e., an external source for the electrodynamic problem. The objective of this paper is to consider the formation of a current pulse during the irradiation of a gas medium by a collimated beam of hard radiation. The method of calculation is described, and the spatiotemporal structure of electromagnetic wave sources moving at the speed of light is calculated. The methods of numerical modeling are applied. The numerical code is devised with the use of the GEANT software package [1], which is widely utilized in nuclear and high-energy physics. Account is taken of the main processes of the interaction of photons with matter (photoabsorption, Compton scattering, and pair production), as well as of the secondary effects of the interaction of delta-electrons with matter and ionization processes induced by the secondary electrons. Electrons with energies lower than ten kiloelectronvolts are not taken into consideration. The input to the code includes the data on the elemental composition of the absorbing region and its geometry, as well as on the spatiotemporal distribution of the primary gamma-ray photons and their momenta. This work is motivated by recent studies on the formation of highly directed, strongly localized (in both space and time) electromagnetic waves by sources propagating at the speed of light [2–8]. Note that, in [2–8], the sources (the current density vectors) were specified heuristically rather than calculated. In calculations of the electromagnetic radiation from nuclear explosions [9, 10], the current density was determined using a simplified model. It was assumed that the electrons produced during absorption of gamma-ray photons by matter keep their initial velocity unchanged along the path of propagation and then stop abruptly. The spread in velocities and ejection angles of the electrons, as well as secondary effects, were neglected. These simplifications had to be made because, at that time, there were no adequate computers and numerical methods.

A schematic of the numerical experiment is shown in Fig. 1. The geometry of the problem is chosen to satisfy the requirements imposed on the spatiotemporal structure of the source by the familiar solutions to the electrodynamic problem of the formation of directed waves [4–8]. A homogeneous absorbing medium is bounded by a cylindrical surface and by two planes that are orthogonal to the cylinder axis, along which a spatiotemporal δ-pulse of primary radiation propagates. The origin of the coordinate system is chosen to be located at the point $O(x = 0, y = 0, z = 0)$, which lies in one of the two planes. The z-axis is assumed to coincide with the cylinder axis. The initial instant is chosen to be the time at which a gamma-ray pulse passes through the boundary of the absorbing region. The results presented below were obtained for 10-MeV gamma-ray photons propagating through air at a pressure of 10 atm. In Fig. 1, the electron trajectories are shown by the solid lines, and the trajectories of gamma-ray photons are represented by the dashed lines. We can see that the electrons are concentrated near the z-axis.

The spatiotemporal distribution of the current density $\mathbf{j}(\mathbf{r}, t)$ is determined by the current density vectors $\mathbf{j}_{\Delta V_i}(\mathbf{r}, t)$ in the volume elements ΔV_i $((x_i, x_i + \Delta x), (y_i, y_i + \Delta y), (z_i, z_i + \Delta z))$ in space. In each of the elements, the current density vectors of individual electrons is summed:

$$\mathbf{j}_{\Delta V_i}(\mathbf{r}, t) = \frac{1}{\Delta V}\sum_{a=1}^{N_i} e\mathbf{v}(\mathbf{r}_a, t),$$

where $\Delta V = \Delta x\Delta y\Delta z$, $\mathbf{v}(\mathbf{r}_a, t)$ and $\mathbf{r}_a(x, y, z, t)$ are the velocities and coordinates of the electrons in an absorbing medium at the time t, and N_i is the number of electrons in the volume element ΔV_i.

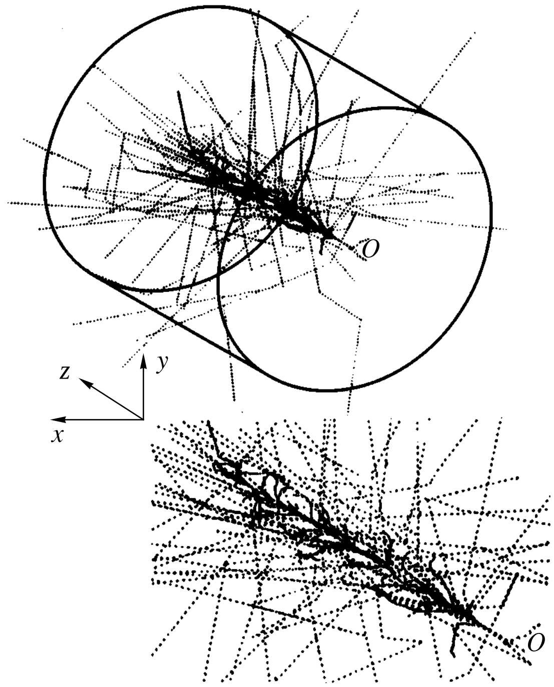

Fig. 1. Schematic of the model experiment. A 20-m long and 20-m-diameter cylindrical region is filled with air at a pressure of 10 atm. The energy of the primary gamma-ray photons is 10 MeV. The solid lines are the electron trajectories, and the dashed lines are the trajectories of gamma-ray photons. The upper frame presents the region around the z-axis on an enlarged scale.

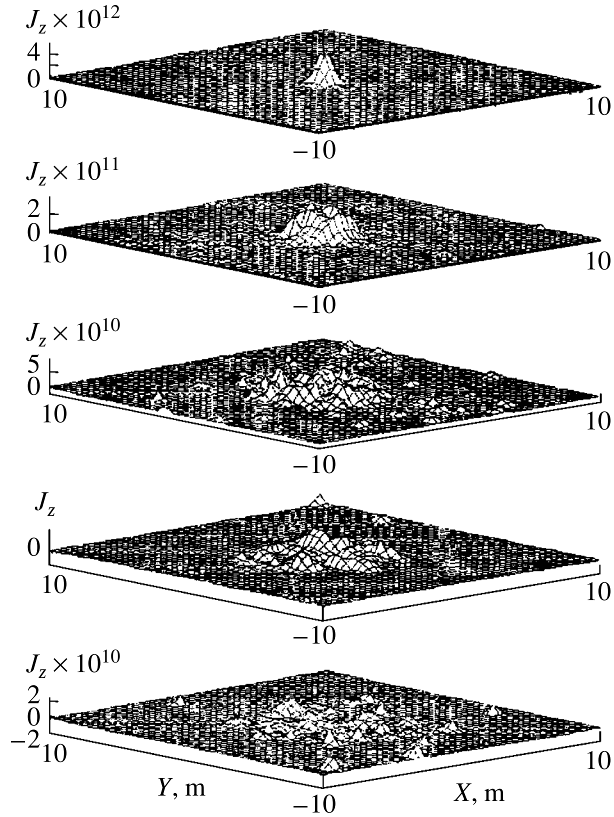

Fig. 2. Histograms of the transverse distributions of the z-component $j_z(\mathbf{r}, t)$ of the current density vector at the time t = 500 ns in the cross sections separated by a distance of 0.2 m along the z-axis.

The centers of the volume element ΔV_i are assigned the vectors $\mathbf{j}_{\Delta V_i}(\mathbf{r}, t)$. The histograms describing transverse distributions of the z-component $j_z(\mathbf{r}, t)$ of the current density vector at fixed t and z are shown in Fig. 2. For the above parameters of the model experiment, the half-width ΔR_1 of the distribution $j_z(\mathbf{r}, t)$ is smaller than 60 cm. This value of ΔR_1 is an estimate of the extent to which the forming source is localized in the transverse direction at the chosen observation time.

Figure 3 shows how the shape of the current pulse changes from cross section to cross section along the absorbing region. For the above parameters of the medium and for the above energy of the primary radiation, the pulse duration T at a level of 0.1 of the peak amplitude is shorter than 2 ns, which corresponds to the spatial extension $\Delta Z_2 = cT < 60$ cm (where c is the speed of light). This value of ΔZ_2 is an estimate of the spatial localization of the current along the z-axis. In Fig. 3, we can also see that the current pulse propagates at the speed of light.

The above estimates of the longitudinal and transverse localization of the pulse enable us to draw the following conclusion: for the chosen parameters of the model experiment, the irradiation of a gas medium by a collimated gamma-ray beam during the time interval under consideration leads to the formation of a spatially localized region that propagates at the speed of light and in which $\mathbf{j}(\mathbf{r}, t) \neq 0$. Hence, a simplified model in which the external source is represented by a delta-pulse of the current propagating at the speed of light along a straight line [7] can be employed in electrodynamic calculations of directed electromagnetic waves.

The method proposed here for calculating the current density vector $\mathbf{j}$ in electrodynamic problems can be used to model other sources propagating at the speed of light (in particular, the sources that give rise to directed waves [5, 6, 11]) by specifying the required distributions of the coordinates and momenta of the primary gamma-ray photons.

The proposed method for calculating the current density vector $\mathbf{j}$ can also be used to determine the shape of a current pulse propagating faster than light (a superluminal source of radiation). An example of the formation of a superluminal source was given in [12], in which the front of a hard radiation pulse was assumed to be incident at an angle to the symmetry axis of an extended absorbing region.

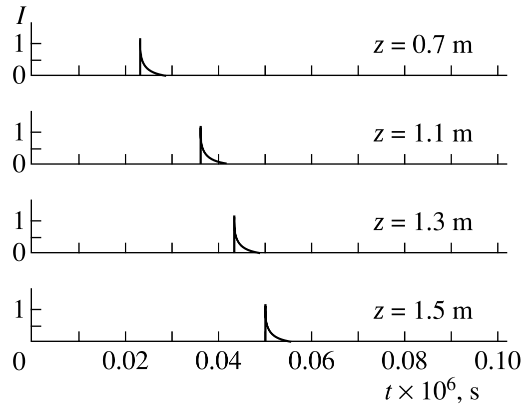

Fig. 3. Waveforms of the current pulse in different cross sections of the absorbing regions for 10-MeV primary gamma-ray photons.

The main results of the present work can be summarized as follows. A method is proposed for simulating an electromagnetic wave source that forms in the interaction of hard radiation with matter and propagates with a speed that is equal to or greater than the speed of light. The transverse and longitudinal localization of the current density vector in a gas medium irradiated by a collimated gamma-ray beam is estimated under the conditions chosen for the numerical experiment. The use of a model in which the external source is represented by a delta-pulse of the current propagating at the speed of light along a straight line is justified.

ACKNOWLEDGMENTS

I am grateful to V.V. Borisov for many useful discussions. This work was supported in part by the Russian Foundation for Basic Research, project no. 99-02-16893.

REFERENCES

1. *GEANT User's Guide*, CERN DD/EE/83-1.
2. P. J. Hillion, J. Math. Phys. **29**, 2219 (1988).
3. P. J. Hillion, J. Math. Phys. **31**, 1939 (1990).
4. P. L. Overfelt, J. Opt. Soc. Am. A **14**, 1087 (1997).
5. P. L. Overfelt and C. S. Kenney, in *Proceedings of the International Symposium on Electron Theory, 1998*, p. 802.
6. V. V. Borisov and A. B. Utkin, J. Phys. A **26**, 4081 (1993).
7. V. V. Borisov and A. B. Utkin, J. Phys. A **27**, 2587 (1994).
8. V. V. Borisov and I. I. Simonenko, Can. J. Phys. **75**, 573 (1997).
9. C. L. Longmire, IEEE Trans. Electromagn. Compat. **20** (1), 3 (1978).
10. W. J. Karzas and R. Letter, Phys. Rev. B **137**, 1369 (1965).
11. N. Brittingham, J. Appl. Phys. **54**, 1179 (1983).
12. F. F. Valiev and V. V. Borisov, in *Proceedings of the International Conference on Nuclear Physics, St. Petersburg, 2000*, p. 379.

Translated by O. Khadin