EFFECTS OF ALTERNATING ELECTRIC FIELD ON CERENKOV RADIATION

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ABSTRACT

For obtaining microwave radiation, we have made close investigations into the effects of alternating electric field on Cerenkov radiation from a charged particle moving with a superphase velocity through an infinite dielectric, as well as a finite one.

Following the suggestion made by Ginzburg[1,2] to use Cerenkov and Doppler effects to obtain microwave radiation, we have applied alternating electric field $\overline{E} = \overline{E}_0 \sin \omega_0 t$ first parallel and then perpendicular to the uniform linear, superphase motion of the charge e through a finite as well as an infinite dielectric and considered the radiation emitted. The field superimposes oscillations on the linear motion of the charge. Consequently, Doppler radiation is given out alongwith the usual Cerenkov radiation. Cerenkov radiation is mainly in the visible region, while discrete frequencies $\omega(\theta)$ emitted through Doppler radiation are restricted to lower frequency region of the electromagnetic spectrum. $\omega(\theta)$, which depend upon field-frequency ω_0, velocity of the incident charge $\overline{v}_0 = \beta_0 c$ and the dielectric, are given by

$$\omega(\theta) = \left| \frac{\pm \ell \omega_0}{\beta n(\omega,\theta) \cos\theta - 1} \right| \qquad (1)$$

where

$$\ell = \pm 1, \pm 2, \cdots, \quad n(\omega,\theta) = \sqrt{\epsilon(\omega,\theta)\mu(\omega,\theta)}$$

the refractive index and θ is the angle of observation.

For an infinite dielectric, the intensity of Cerenkov radiation is found to be[3]

for $\overline{E} // \overline{v}_0$

$$I_{cer} = I_c \left[J_0^2(\lambda\omega_m) + J_1^2(\lambda\omega_m) \right] \qquad (2)$$

and for $\overline{E} \perp \overline{v}_0$

$$I_{cer} = \frac{I_c'}{\pi} \sum_{n=0}^{\infty} \frac{(-1)^n \Gamma^2(n+\frac{1}{2})}{(n+1)\Gamma^4(n+1)} \cdot (\alpha\lambda\omega_m)^{2n} \qquad (3)$$

where

$$I_c = \frac{\mu e^2 v_0^3}{c^2 v^3} \left(\frac{v_0}{v} - \frac{1}{\epsilon\mu\beta^2} \right) \frac{\omega_m^2}{2}$$

$$I_c' = \frac{\mu e^2}{c^2} \cdot \frac{\omega_m^2}{2} \cdot \left(1 - \frac{1}{\epsilon\mu\beta_0^2} \right), \quad v = |\overline{v}_0 + \overline{v}_n|$$

$$\alpha = \sqrt{\epsilon\mu\beta_0^2 - 1}, \quad \lambda = v_n / \omega_0 v_0, \quad v_n = \frac{e E_0}{m \omega_0},$$

J_0, J_1 denote Bessel function and ω_m is the maximum frequency upto which Cerenkov radiation condition is satisfied.

Both these results show that in presence of parallel as well as perpendicular alternating electric field Cerenkov radiation has an oscillatory behaviour and that it gets reduced from its no-field-value. Actual variation of the intensity of Cerenkov radiation with $x = \lambda\omega_m$ is studied.

Further, in the case of an infinite dielectric the intensity of Doppler radiation is found to be for $\overline{E} // \overline{v}_0$

$$I_{Dop} = 2 I_c \sum_{\ell=1}^{\infty} \left\{ J_\ell^2(\lambda\omega_m) - J_{\ell-1}(\lambda\omega_m) \cdot J_{\ell+1}(\lambda\omega_m) \right\} \qquad (4)$$

and for $\overline{E} \perp \overline{v}_0$

$$I_{Dop} = \frac{2 I_c'}{\pi} \sum_{\ell=1}^{\infty} \sum_{n=0}^{\infty} \frac{(-1)^n \Gamma^2(n+\ell+\frac{1}{2}) \cdot (\alpha\lambda\omega_m)^{2n+2\ell}}{n! \, \Gamma^2(n+\ell+1) \cdot \Gamma(n+2\ell+1) \cdot (n+\ell+1)} \qquad (5)$$

The results (4) and (5) show that (i) Doppler radiation is a field-effect, (ii) it has an oscillatory behaviour and (iii) the number of Doppler modes increases with x. Actual variation of intensity of Cerenkov radiation and different modes of Doppler radiation ($\ell = 1, 2, \cdots 5$) with various parameters is studied and a comparison of the results for parallel and perpendicular fields is made. It gives the following conclusions: i) the parallel field reduces Cerenkov radiation more effectively than the perpendicular one ii) the intensity of different modes of Doppler radiation given out in presence of perpendicular field is weaker than the intensity of corresponding modes of Doppler radiation emitted when the field is parallel and iii) the number of Doppler modes emitted in presence of perpendicular field is less than that with the parallel one.

Further, it is found that the total radiation-loss, through Cerenkov and Doppler radiation, in presence of parallel as well as perpendicular alternating electric field, in an infinite dielectric, is constant and that it is always equal to the energy radiated through Cerenkov radiation in absence of field. Therefore, the ultimate effect of alternating electric field is to shift the radiation energy from the visible to lower frequency regions (which is higher than the applied field frequency) of the electromagnetic spectrum.

When a charge moves through an infinite dielectric, energy lost by the charge through ionization, excitation and atomic collisions etc. is quite large, compared to energy-loss due to Cerenkov radiation. For minimizing the energy-losses of the charge by processes other than the Cerenkov effect, we have taken into account the effects of alternating electric field on Cerenkov radiation when a charge moves above a boundary separating two dielectrics. We have tackled the problem by using the method of images and derived results for intensities of Cerenkov and Doppler radiations in closed forms. The effects of boundary on Cerenkov radiation in presence of parallel and perpendicular alternating electric fields are discussed in detail under the following physical situations of interest.

(I) When the charge moves in vacuum at a height h ($h \neq 0$) from the surface of a dielectric, the intensity of Cerenkov radiation is obtained in a closed form and it is found that the intensity of Cerenkov radiation is inversely proportional to the square of the height h. A numerical calculation

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shows that the intensity of Cerenkov radiation in this situation is at least 2 to 3 orders less than that in the usual one, when the charge moves through an infinite dielectric. Variation of intensity of Cerenkov radiation with (i) field parameter

$$\chi' = \frac{eE_0}{4mh\omega_0^2\sqrt{1-\beta_0^2}} , \qquad \text{for a fixed h}$$

and
(ii) height h, for a fixed x
is studied in detail. One can choose the height h at which one should pass the electron-beam, so that the unwanted energy-losses of the charge are minimized.

(II) When the charge moves exactly along the surface of a dielectric i.e. (h = 0), the intensity of Cerenkov radiation is obtained in a closed form.

In absence of field the results agree exactly with Eq. (18) of Sitenko and Tkalich[4]. A numerical calculation shows that the intensity of Cerenkov radiation in this situation is about 60% of the intensity when the charge moves through an infinite dielectric.

The results show that transfer of Cerenkov intensity to the Doppler radiation may find possible use in the microwave region or that frequency region below the visible region which is otherwise inaccessible.

References:

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4) Sitenko, A.G. and Tkalich, V.S. (1960) Sov. Phys. - Tech. Phys. 4, 981.

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