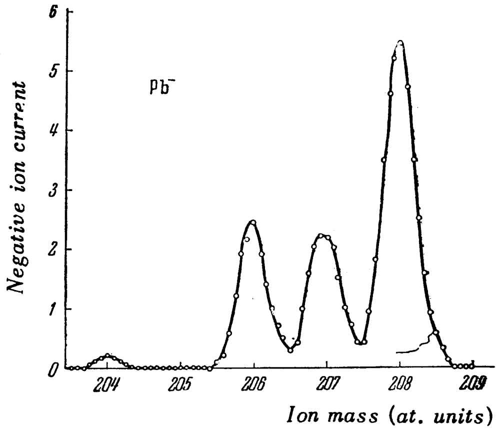
by extrapolating the electronic binding energy in isoelectronic sequences of atoms and ions calculated the electron affinity of a number of light elements, gives 1.7 ev for this quantity in Si.



Germanium. For this element we tested the possibility of producing negative ions by "charge exchange" between negative antimony ions and germanium atoms. The source was equipped with two vaporizers: one for the volatilization of germanium and the other for the vaporization of antimony. The germanium vapor at $< 5 \times 10^{-4}$ mmHg pressure consists principally of atoms;[6] therefore it could be expected that the process of "charge exchange" would produce negative atomic ions of germanium. When the ion source chamber contained only germanium vapor negative ions were not observed. When the source also contained antimony vapor we detected negative ions of this element (Sb^-, Sb_2^-, Sb_3^-) and Ge^- ions (70,72, 73, 74, 76). The Ge^- lines were identified by comparison with the Sb^- (121, 123) lines and by the relative intensities of the individual isotopes.

Tin. The ion source contained $SnCl_4$ vapor. Negative ions were produced by 80 ev electrons in a 4 mA electron current. The negative ion spectrum contained, in addition to Cl^- and Cl_2^- ions, the ions Sn^-(112, 114, 116, 117, 118, 119, 120, 121, 124), $SnCl^-$, $SnCl_2^-$, $SnCl_3^-$ and $SnCl_4^-$.

Negative Sn^- ions were also obtained by "charge exchange" of negative bismuth ions and tin atoms. But it was not possible to resolve all of the tin isotopes in the mass spectrometer.

Lead. The working substance in the ion source was PbI_2 vapor. The electron energy was 40 ev and the electron current 2 mA. The negative ion spectrum contained the lines of I^-, Pb^- (204, 206, 207, 208), I_2^-, PbI^- and PbI_2^-. The Pb^- ions were identified by comparison with the I ions and by the relative isotopic intensities. The Figure shows the mass spectrogram of Pb^- ions obtained by plotting different ion energies with constant magnetic field strength of the analyzer. The Figure shows that the lead isotopes are well resolved and the height of the individual peaks corresponds to the relative isotopic abundances in ordinary lead.

We also performed an experiment to obtain Pb^- ions by "charge exchange" between antimony ions and lead atoms. When lead and antimony vapor were simultaneously introduced into the ion source the negative ion spectrum revealed a broad line for Pb^- ions which were not resolved into isotopes.

The atoms of C, Si, Ge, Sn and Pb which form the Iv *B* subgroup of the periodic table possess two *p*—electrons in their outer electron shells. The electron affinity of these elements must be attributed, as for the elements of groups V, VI, and VII, to the existence of an incomplete group of equivalent *p*—electrons into which the extra electron is introduced.

1 L. G. Smith, Phys. Rev. 51, 263 (1937).
2 R. E. Honig, J. Chem. Phys. 22, 126 (1954).
3 V. M. Dukel'skii, Dokl. Akad. Nauk SSSR 105, 595 (1955).
4 R. H. Vought, Phys. Rev. 71, 93 (1947).
5 D. R. Bates, Proc. Roy. Irish, Acad. A51, 151 (1447).
6 R. E. Honig, J. Chem. Phys. 21, 573 (1953).

Translated by I. Emin
94

Peculiarities of Cerenkov Radiation in Anisotropic Media

V. E. PAFOMOV
P. N. Lebedev Physical Institute, Academy of Sciences, USSR
(Submitted to JETP editor July 27, 1956)
J. Exptl. Theoret. Phys. (U.S.S.R.) 32, 366-367 (February, 1957)

THE problem of Cerenkov radiation in anisotropic media has been discussed in a series of articles[1-6]. Here we turn our attention to those interesting peculiarities that were not pointed out in the enumerated articles. For the sake of simplicity we consider these peculiarities in the case of a charge moving along the optic axis of a uniaxial dielectric crystal.

Taking the *z* axis along the velocity we obtain, according to Ref. 2, the Fourier component of the vector potential at large distances from the trajectory of the particle ($|\sigma r| \gg 1$) in the following form

$$A_{z\omega} = \frac{e}{c\sqrt{2\pi\sigma r}} \exp\{i(k_z z + k_r r - \omega t)\} \quad (1)$$

$$= \frac{e}{c\sqrt{2\pi\sigma r}} \exp\{i(z - vt)\omega/v \pm isr\},$$

$$\sigma^2 = (\omega/v)^2[1 - \beta^2\varepsilon_r(\omega)]\varepsilon_z(\omega)/\varepsilon_r(\omega) = -s^2. \quad (2)$$

The original Bessel equation (see Ref. 2) contains σ^2; therefore (1) is a solution independent of the sign of σ. The choice of the sign is determined by the requirement that the field must vanish at infinity. But in the absence of attenuation in the medium this criterion is insufficient. Again it is necessary to require that the Poynting vector be directed away from the radiating system. This implies a positive component W_r of the group velocity. In anisotropic media there is a range of frequencies where an outflow of energy from a moving charge ($W_r > 0$) corresponds to advanced potentials, which must also be taken as the type of the solution.

An analogous situation occurs in the refraction of plane waves incident upon a dielectric from vacuum. As is known, two refracted waves satisfy the boundary conditions. Usually one takes that wave whose wave vector forms an acute angle α with the normal to the interface pointing into the dielectric. In the region of negative group velocity, however, energy is carried out of the boundary by a wave with a wave vector that forms an obtuse angle $(\pi - \alpha)$ with the normal. As Mandelshtam[7] has remarked, the direction of energy flow must also be a criterion in choosing the refracted wave.

We calculate the radial component of the group velocity by means of a formula, which has been derived in Ref. 8, and obtain

$$W_r = \partial\omega/\partial k_r = n^2 c \sin\vartheta/\varepsilon_z(n + \omega\partial n/\partial\omega), \quad (3)$$

where ϑ is the angle between the wave vector and the z axis, and n is the refractive index for the extraordinary wave (see Ref. 1). Unattenuated waves will exist only for a real refractive index n. If $\epsilon_r(\omega)$ and $\epsilon_z(\omega)$ depend on the frequency in the same way as, e.g., in Ref. 2, then the derivative $\partial n/\partial\omega$ is positive over the entire frequency range. Thus the region of negative group velocity is determined only by the sign of $\epsilon_z(\omega)$ ($\epsilon_z < 0$), in which case it is necessary to take advanced potentials ($k_r < 0$) as the type of the solution.

If retarded potentials are taken as the type of the solution over the entire frequency range, then the force acting on the particle will have the form

$$F_z = -(e/c)^2 \int [1 - (1/\varepsilon_r(\omega)\beta^2)]\,\omega d\omega, \quad (4)$$

where the integration is carried out over the region σ^2. Just that frequency range, where the parentheses in the integrand remains negative, corresponds to the range with negative group velocity. Here it is necessary to take advanced potentials as the type of the solution, which leads to formula (4) with the modulus of the integrand.

Another peculiarity of Cerenkov radiation in crystals is that the angle γ between the light ray W and the direction of electron motion may be larger than 90°. To show this we write

$$\operatorname{tg}\gamma = \frac{W_r}{W_z} = \frac{\partial\omega/\partial k_r}{\partial\omega/\partial k_z} = \frac{\varepsilon_z}{\varepsilon_r}\operatorname{tg}\vartheta.$$

In the region of negative group velocity we have $k_r < 0$; therefore $\tan\vartheta = k_r/k_z < 0$ and $\tan\gamma > 0$. Hence the charge radiates at velocities smaller than a certain value in accordance with the radiation condition $\epsilon_r\beta^2 < 0$.

In the region where $\epsilon_r > 0$ and $\epsilon_z < 0$ the charge radiates at any velocity. Here we have $\tan\vartheta > 0$ and ϵ_z and ϵ_r have different signs; therefore $\tan\gamma < 0$, i.e., the light ray (the direction of energy propagation) forms an obtuse angle with the direction of electron motion. It is obvious that these peculiarities occur also in the most general case.

In conclusion the author expresses deep gratitude to V. L. Ginzburg for valuable instructions and a discussion of the results and to B. M. Bolotovskii for a discussion of the results of this work.

---

1 V. L. Ginzburg, J. Exptl. Theoret. Phys. (U.S.S.R.) 10, 608 (1940).
2 A. Kolomonskii, Dokl. Akad. Nauk SSSR **86**, 1097 (1952).
3 M. I. Kaganov, J. Tech. Phys. (U.S.S.R.) **23**, 507 (1953).
4 Katsumi Tanaka, Phys. Rev. **93**, 459 (1954).
5 A. G. Sitenko and M. I. Kaganov, Dokl. Akad. Nauk SSSR **100**, 681 (1955).
6 V. E. Pafomov, J. Exptl. Theoret. Phys. (U.S.S.R.) **30**, 761 (1956); Soviet Physics JETP **3**, 597 (1956).
7 L. I. Mandelshtam, J. Exptl. Theoret. Phys. (U.S.S.R.) **15**, 475 (1945).