KINETICS OF UNIPOLAR CHARGING OF BETA-ACTIVE “HOT” PARTICLES IN AN ELECTRIC FIELD

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KINETICS OF UNIPOLAR CHARGING OF BETA-ACTIVE "HOT" PARTICLES IN AN ELECTRIC FIELD

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In previous works ([1], [2]), the phenomenon of unipolar charging of aerosol particles with high individual radioactivity due to electron emission accompanying alpha and beta decay was considered. The aim of the present work was to study the kinetics of such charging of beta-active "hot" aerosol particles in an external electric field. This is prompted by interest in the behavior of such particles in electrostatic precipitators and in electric fields occurring in the terrestrial or industrial atmosphere.

Let us represent an aerosol particle as an absorbing sphere of radius r_0, located at a distance R from a negative electrode that creates a uniform electric field E_0, sufficient for neglecting ion diffusion throughout the space surrounding the particle. If the charging process of the particle is assumed to be quasistationary, then the rate of change of its charge Z with time t may be expressed in the form

$$dZ/dt = I - J\_(Z), \tag{1}$$

where I is the flux of electrons from the particle, equal to its radioactivity, and $J\_(Z)$ is the flux onto it of negative gas ions produced in the surrounding space by these electrons. The latter obviously depends not only on the particle charge Z, but also on the external electric field E_0, and is equal to the number of negative ions arising per unit time in the volume bounded by the sphere R and the limiting trajectory, along which an ion, moving in the given external field and particle charge, still reaches it (see Fig. 1). Under the condition that the external field at the particle surface is several times smaller than the field of the charge Z, its polarization may be neglected. In this case the differential equation of the limiting trajectory in polar coordinates r and θ will be as follows:

Fig. 1. Diagram for calculating the kinetics of particle charging in an external electric field

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Fig. 2. Diagram of the charging-precipitating device

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$$dr/d\theta = -rE(r)/E(\theta), \tag{2}$$

where $E(r) = eZ/r^2 - E_0 \cos\theta$ is the simple sum of the particle field and the component of the external field in the direction r; $E(\theta) = -E_0 \sin\theta$ is determined only by the external field. The integral of (2), with the boundary condition $eZ/r^2(\pi) = E_0$, meaning equality of the particle field to the external field at point a (see Fig. 1), has the form

$$r = \left(\frac{2eZ}{E_0} \frac{1}{1 - \cos\theta} \right)^{1/2}. \tag{3}$$

The flux of negative ions onto a particle can now be expressed in the form

$$J\_(Z) = \frac{I\bar{r}}{\lambda} = \frac{I}{4\pi\lambda} \iiint\limits_V \sin\theta \, d\theta \, dr \, d\varphi, \tag{4}$$

where $\bar{r}$ is the mean radius over the volume bounded by the distance R to the electrode producing the external field and by the limiting trajectory, and λ is the mean distance between pairs of ions formed by high-energy electrons emitted from the particle. For $R \geq 10^{-2}$ cm, the following expression for the flux, not containing R, is obtained:

$$J\_(Z) = \frac{I}{\lambda} \left[2 \left(\frac{eZ}{E_0} \right)^{1/2} - r_0 \right]. \tag{5}$$

Fig. 2. Diagram of the charging-precipitating device

Substituting now (5) into (1) and integrating with respect to t from the initial charge Z_0, we obtain the equation for the kinetics of particle charging in an external electric field

$$\xi = 1 - (1 - \xi_0) \exp\left\{ - \left[\xi - \xi_0 + \frac{I(1 + r_0/\lambda)}{2Z(\infty)} t \right] \right\}, \tag{6}$$

where the dimensionless parameter ξ^2 is equal to the ratio of the particle charge at any time $Z(t)$ to the limiting charge $Z(\infty)$ that the particle can acquire while in the field E_0.

This limiting charge can be calculated as

$$Z(\infty) = (\lambda + r_0)^2 E_0 / 4e. \tag{7}$$

It is evident that this charge is proportional to the external field, does not depend on the radioactivity of the particle, and depends only weakly on its radius, since the latter is much smaller than λ. The time required to attain such a charge can be estimated as $t > 2Z(\infty)/I$.

The experimental study of the kinetics of charging of beta-active "hot" particles in an electric field was carried out on the apparatus described earlier ([2]). A suspension in acetone of spherical particles of glass and ion-exchange resin, 1-6 μ in size and with individual activity 10^{-10}-10^{-8} curie, was sprayed into a vertical column 17 cm in diameter and 300 cm high. The aerosol was kept in the column for 10-15 min for the particles to acquire stationary charges without an external field and then entered the charging-precipitating device shown in Fig. 2. Additional charging of the particles in the electric field occurred during their motion in a plane-parallel capacitor with an interelectrode gap of 1 cm and a length of 50 cm. The aerosol jet was introduced midway between the electrodes through a flat channel with a cross section of 2 × 50 mm, swept by a stream of clean air whose velocity was selected so that no blurring of the aerosol jet occurred. The velocity of the aerosol jet was 4.5 cm/sec and corresponded to the maximum of the Poiseuille flow profile.

Fig. 3. Beta radiograms of the electrodes. *a* –the "hot" field electrode; *b* –the negative electrode. The arrow indicates the direction of the air flow.

tion, and the residence time of the particles in the charger was 11 sec. To prevent deposition of particles on the electrodes of the charger, the electric field in it was commutated at a frequency of 100 Hz. The particles then entered the plane-parallel deposition section through a narrow slit at the positive electrode, at a distance of 50 cm from the inlet, where a Poiseuille flow profile had time to become established. The length of the deposition section was 180 mm, the distance between the electrodes was 10 mm, and the inlet slit was 1 mm. A constant voltage of 10 kV was applied to the electrodes of the deposition section. The electrodes were glass plates on which a transparent conducting layer of aluminum had first been deposited.

Figure 3 shows beta radiograms of the positive and negative electrodes of the depositor, obtained in one of the experiments. It is evident that the highly active particles were deposited on the negative electrode, and the more rapidly the greater their radioactivity was. The electrodes and radiograms were superposed so that, with the aid of a microscope with a measuring stage, the size of each particle was measured; from the coordinate of its deposition its charge was

Fig. 4

Figure 3: Fig. 4

determined, and from the diameter of the corresponding spot on the radiograms its radioactivity was determined.

Fig. 4. Dependence of the mean charge of particles acquired by them in an electric field of various field strengths on their radioactivity. $\sigma = 1.2$; $\lambda = 18\ \mu$, $\Delta t = 11$ sec. The points show experimental results (a—550 V/cm; b—160; v—100; g—48; d—24 V/cm); the curves were calculated from equation (6).

In Fig. 4, the points show the experimentally found dependences of the mean values of the positive charges of particles that were in electric fields of 24, 48, 100, 160, and 550 V/cm on their radioactivity. The solid lines show the same dependences calculated from equation (6). The flux of electrons from the particles was taken as $I\sigma$, where σ is a coefficient allowing for the error in measuring the radioactivity from the diameter of the spot on the radiograms, as well as the possible contribution to the flux from secondary electrons. The value of λ was calculated from equation (6) for the point with coordinates $I = 90$ disintegrations/sec, $Z = 400$ electrons. It is seen that formula (6) satisfactorily describes the charging kinetics of "hot" beta-active particles situated in an external electric field.

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1. V. D. Ivanov, V. N. Kirichenko, I. V. Petryanov, DAN, **182**, No. 2 (1968).
2. V. D. Ivanov, V. N. Kirichenko, DAN, **188**, No. 1 (1969).

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