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PHYSICS

1969

SovietRxiv

Abstract

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UDC 541.182.2/3

PHYSICS

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(Presented by Academician I. V. Petryanov, 19 IX 1968)

In a previous work [1] it was shown that alpha-active aerosol particles whose individual radioactivity reaches 10^{-11} curie are distinguished by the ability to acquire stationary positive charges as a consequence of the emission, accompanying alpha decay, of electrons from the particles. The purpose of the present work was to study the regularities of such charging for beta-active aerosol particles.

Let us represent an aerosol particle as an absorbing sphere of radius r_0, located at the center of an likewise absorbing sphere of considerably larger radius R, which, however, does not exceed the maximum range of the electrons emitted by the particle. Their flux from the particle is equal to its radioactivity I. In the stationary state it must be compensated by the diffusion fluxes to the particle of negative $J_-(Z_0)$ and positive $J_+(Z_0)$ gas ions, generated in the surrounding space by the high-energy electrons emitted from the particle,

$$I = J_-(Z_0) - J_+(Z_0). \tag{1}$$

These fluxes are functions of the mean value of the stationary charge of the aerosol particle that interests us, eZ_0, where e is the elementary charge and Z_0 is their number.

To calculate the ionic fluxes we shall use the method of the probability function for reaching the boundary by a Brownian particle, proposed by A. N. Kolmogorov and M. A. Leontovich [2]. In our case this will be the probability that ions, formed in the surrounding space, reach the spherical particle. If the mean distance λ from the surface of the particle at which the ions nearest to it are formed is much greater than its radius r_0, then the required probability satisfies the stationary diffusion equation

$$D\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial W}{\partial r}\right) + BF(r)\frac{\partial W}{\partial r} = 0. \tag{2}$$

Here D and B are the diffusion coefficient and mobility of the gas ions. The second term takes into account the drift of ions in the field of the central force

$F(r)$. Neglecting image forces and taking into account the boundary conditions $W(r_0) = 1$ and $W(R) = 0$, we obtain the solution in the form of a function of the energy parameter α/r:

$$W_{+,-}(r) = \frac{\exp(\pm\alpha/R) - \exp(\pm\alpha/r)}{\exp(\pm\alpha/R) - \exp(\pm\alpha/r_0)}; \qquad \alpha = \frac{Be^2Z_0}{D} = \frac{e^2Z_0}{kT}. \tag{3}$$

Assuming the ion source to be linear with uniform density $1/\lambda$, we obtain the expression for the fluxes of positive or negative ions:

$$J_{+,-} = \frac{I}{\lambda}\int_{r_0}^{R} W_{+,-}(r)\,dr =$$

$$= \frac{I}{\lambda}\left\{\frac{\pm\alpha/r_0}{\exp(\pm\alpha/r_0) - \exp(\pm\alpha/R)}\left[\mathrm{Ei}(\pm\alpha/r_0) - \mathrm{Ei}(\pm\alpha/R)\right] - 1\right\}, \tag{4}$$

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Fig. 2. Beta radiograms of the electrodes: *a* –positive electrode, *b* –negative electrode. The arrow indicates the direction of the air flow.

where the integral of the probability function is expressed in terms of Euler functions with the same energy parameter α/r. Since, for the large charges of particular interest, $\alpha/r_0 \geq 3$, and at the same time the condition $\alpha/R \ll 1$ is always maintained, the difference between the fluxes of negative and positive ions can be expressed by the simple asymptotic formula

$$J_- - J_+ = \frac{Ir_0}{\lambda}\left(\frac{\alpha}{r_0}\ln\gamma\frac{R}{\alpha} - 1\right) \simeq \frac{I\alpha}{\lambda}\ln\frac{R}{\alpha}, \tag{5}$$

where, moreover, the Euler constant γ and unity may be neglected.

From (5) and (1) one now obtains an expression for calculating the mean value of the stationary charge,

$$\lambda kT/e^2Z_0 = \ln\left(RkT/e^2Z_0\right). \tag{6}$$

It is seen that Z_0 depends neither on the size of the particle nor on the radioactivity, and depends only weakly on the distance to the absorbing sphere R. The result is understandable, since the fluxes of charges from the particle and back are a consequence of one and the same cause—its own radioactivity—while the sphere of action of the electric force considerably exceeds its radius r_0.

Calculation by formula (6) shows that an aerosol particle emitting electrons with an energy of 1 MeV and located at the center of a sphere of radius 1 m must acquire a mean stationary positive charge equal to 150 elementary charges.

Fig. 1. Schematic of the apparatus.

Figure 1: Fig. 1. Schematic of the apparatus.

Fig. 3. Dependence of the positive charges of particles on their own beta activity for different size ranges. Particle radius: a—4-5 μ; b—3-4 μ; c—2-3 μ; d—1-2 μ

Figure 2: Fig. 3. Dependence of the positive charges of particles on their own beta activity for different size ranges. Particle radius: a—4-5 μ; b—3-4 μ; c—2-3 μ; d—1-2 μ

The presence of external sources of ionizing radiation must, however, limit the possibility of acquiring such charges, independently of the radioactivity of the particles. For example, under free-atmosphere conditions formula (6) is applicable for a particle activity greater than 10^{-11} curie, which in a surprising way coincides with the threshold above which beta-active particles are commonly considered "hot" from the biological point of view. Calculation of the mean stationary charge for alpha-active aerosol particles containing radium A (polonium-218), by combining (1) and (3), shows that it must be close to 10 elementary charges. This agrees with data we obtained earlier (1).

Fig. 1. Schematic of the apparatus. 1—column; 2—pneumatic atomizer; 3—ampoule with a suspension of particles in acetone; 4—temperature sensor; 5—manometer; 6—heater; 7—air filters; 8—flowmeters; 9—electrostatic precipitator; 10—air filters.

The time t required for aerosol particles to attain the stationary charge can be estimated from the condition $It > Z_0$.

The stationary charges of beta-active "hot" particles were determined by us experimentally. For this purpose we used spherical particles of radius 1-6 μ made of glass and ion-exchange resin, activated with gold-198, emitting electrons with a maximum energy of 0.96 MeV. Onto particles placed on a glass substrate, in vacu-

a layer of stable gold about $\sim 0.1\,\mu$ thick. The particles were then washed off the substrate and irradiated in a flux of thermal neutrons $\sim 10^{13}$ n/cm$^2 \cdot$ s. The radioactivity of the particles was determined by autoradiography from the diameter of the spot, and individual control particles were measured with a 2π-flow methane counter. The radioactive aerosol was obtained by spraying a suspension of the particles in acetone, previously treated with ultrasound in order to separate the particles from the vessel walls and from one another. In this process the gold shells were partly stripped off, especially from particles of the resin that swelled in acetone. As a result, for each particle size there was a fairly broad range of radioactivities.

Fig. 3. Dependence of the positive charges of particles on their own beta

Fig. 4. Dependence of the positive charges of particles whose intrinsic radioactivity exceeds 50 decays/sec on their radius

Figure 3: Fig. 4. Dependence of the positive charges of particles whose intrinsic radioactivity exceeds 50 decays/sec on their radius

activity for different size ranges. Particle radius: a–$4 \div 5\,\mu$; b–$3 \div 4\,\mu$; c–$2 \div 3\,\mu$; d–$1 \div 2\,\mu$.

Figure 1 shows the layout of the apparatus. The particle suspension was sprayed in the upper part of column 1, 300 cm high and 17 cm in diameter. After being held for 10-15 min, the particles were entrained by a stream blowing around the bottom of the column and were introduced into a plane-parallel electrostatic precipitator through a small gap at the positive electrode. The length of the forming part of the precipitator was 500 mm, that of the collecting part 180 mm, the distance between the electrodes was 10 mm, the inlet gap was 1 mm, and the voltage on the electrodes was 10 kV. The electrodes were glass plates on which a transparent conducting layer of aluminum had previously been deposited.

Figure 2 gives beta radiograms of the positive and negative electrodes. It is seen that all highly active aerosol particles were deposited on the negative electrode. The electrodes and radiograms were superposed so that, with the aid of a microscope, it was possible simultaneously to measure the particle diameter, the diameter of the corresponding radiograph, and the coordinate of particle deposition, i.e., to determine its radioactivity and charge.

Figure 3 shows the dependences, obtained in one of the experiments, of particle charges on their radioactivity for different size ranges. It is seen that at activities greater than 50 disintegrations/s the particle charges do not depend on the activity and lie in the range 130-300 elementary charges, which is in satisfactory agreement with calculations by formula (6). The decrease in charges at lower activity is apparently due to the influence of external radiation sources (from the walls and from the volume of the column). However, in contrast to formula (6), the particle charge turned out to depend to a considerable degree on their size, which is clearly seen from Fig. 4 for particles whose charge did not depend on radioactivity. As approximate calculations show, this is a consequence of the "escape" of particles under the action of gravity from their own ionic atmosphere.

It turned out that the distribution of the experimentally found stationary charges agrees well with the normal law. Thus, for 142 particles of radius 4-5 μ, the mean charge is 310 elementary charges, and the standard deviation is 37 elementary charges.

Thus, it has been shown theoretically and experimentally that beta-active "hot" particles in the micron size range, in contrast to weakly active ones, spontaneously acquire stationary positive

Fig. 4. Dependence of the positive charges of particles whose intrinsic radioac-

tivity exceeds 50 decays/sec on their radius

charges, which are a consequence of electron emission and depend on the particle size, but do not depend on their intrinsic radioactivity, if it exceeds the threshold determined by external radiation sources. This phenomenon can be used for the selective trapping of "hot" beta-active aerosol particles by means of an electric field.

Received
12 VIII 1968

CITED LITERATURE

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Note: Figure translations are in progress. See original paper for figures.