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**GENERATION OF A NARROW BIPOLAR CHARGE
DISTRIBUTION ON AEROSOL PARTICLES**

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Electrical classification. Requirements to input aerosol.

Monodisperse aerosols are necessary for the calibration of aerosol measurement devices as well as for experimental investigation of physical processes in aerosols. Currently, the method of electric separation is used for the generation of such aerosols, especially in the submicron range [1,2,9,10]. A narrow fraction is separated from particles which carry one elementary charge e (positive or negative). Multiply charged particles which are carried to the outlet of the separator widen the size spectrum of the separated aerosols. To estimate the suitability for electric separation of a particle charge distribution it is expedient to use two quality criteria.

$$\xi = \frac{n_1}{\sum_{j=2}^{\infty} n_j}, \quad (1)$$

$$\xi_0 = n_1/N. \quad (2)$$

Here n_j denotes the numeric concentrations of the particles carrying j elementary charges of one polarity, N - the total numeric concentration of particles. The growth of ξ is accompanied by a decrease of the risk of widening of the output aerosol spectrum on the account of multiply charged "alien" particles; the growth of ξ_0 leads to an increase of the concentration of the output aerosol. The criterion ξ is a reciprocal of an analogous criterion ξ proposed for the estimation of the quality of separated aerosol in [1].

For electrical separation usually aerosols with a stationary charge distribution are used, such a distribution occurs when the value of the charging parameter [3]

$$a_{(\pm)} = \frac{1}{\epsilon_0} \int_0^{t_q} \lambda_{(\pm)}(t) dt \quad (3)$$

is sufficiently large for the ions of both polarities. Here $\lambda_{(\pm)}$ is the polar conductivity of the air, t_q - the time the aerosol is in a bipolar ionic atmosphere, ϵ_0 - the electric constant. The stationary distribution arises independently of the initial state of the aerosol; for particles which are not very small (radius $r \gg 0.2 \mu\text{m}$) the stationary probability distribution is similar to the Boltzmann distribution [1].

The stationary distribution is rather wide and thus the values of the criteria ξ and ξ_0 are relatively small and decreasing with the increase of particle size. In an initially uncharged or weakly charged aerosol it is possible to obtain a narrower particle charge distribution. For this purpose it is necessary to guarantee small values of the parameters $a_+ \approx a_-$ in the charging device. This is possible in a charger with an ionizer which can be switched off. At some initial moment in such a charger an initial concentration ν_0 of ions of both signs is created. This concentration will then fade due to the recombination of ions of both signs with one another and with aerosol particles. After the consumption of all ions the elementary processes of charge exchange cease and the resulting charge distribution of aerosol particles will be maintained. We will call this distribution the output distribution of the charger.

Theory of the charging process

Following Fuchs [4] we will designate with p_j the probability that a particle which carries j elementary charges, catches one ion of the same sign in a unit of time at the unit concentration of these ions; q_j will be used to designate the probability of such a particle catching an ion of the opposite sign under the same conditions. Then, assuming that $p_j = p_{-j}$, $q_j = q_{-j}$ and that the initial concentrations of the ions of both signs are equal $\nu_0^+ = \nu_0^- = \nu_0$ which ensures the symmetry of the charge distribution of particles at any one moment, the process of particle charging can be described by the system (4) of kinetic equations. In this system n_j denotes the concentration of the particles carrying j elementary charges (according to the above assumption $n_j = n_{-j}$), a is the coefficient of mutual recombination of ions, and g is the aerosol electric density [5]. Theoretically $m \rightarrow \infty$, at practical solving of the system it is necessary to choose a sufficiently large value.

$$\left. \begin{aligned}
 \frac{dn_0}{dt} &= v(2n_1q_1 - 2n_0p_0), \\
 \frac{dn_j}{dt} &= v(n_{j-1}p_{j-1} - n_jp_j - n_jq_j + n_{j+1}q_{j+1}), \\
 & \quad j = 1, 2, \dots, m-1, \\
 \frac{dn_m}{dt} &= v(n_{m-1}p_{m-1} - n_m p_m - n_m q_m), \\
 \frac{dv}{dt} &= -\alpha v^2 - gv.
 \end{aligned} \right\} (4)$$

The aerosol electric density takes into account all processes of ion loss due to their adsorption to particles; it can be calculated by the equation

$$g = \sum_{j=1}^m n_j(p_j + q_j). \quad (5)$$

The system (4) was solved numerically on a computer using the method of Runge-Kutta for the particle radius $r = 0.6 \mu\text{m}$. The values p_j , q_j were calculated according to the theory of Fuchs [4], the values $\alpha = 1.6 \cdot 10^{-12} \text{ m}^3/\text{s}$ and $m = 5$ were used. The solution shows that the output distribution of the charger is fully determined by the ratio v_0/N ; if $v_0/N \geq 50$, then this distribution is practically stationary. Table 1 compiled on the basis of the results of solving (4) presents the dependencies of the criteria ξ and ξ_0 on the ratio v_0/N . The difference of the obtained final distribution from the Boltzmann distribution can be explained by the low selected value of $m = 5$.

Table 1
Dependence of the calculated values of ξ and ξ_0 on the ratio v_0/N

v_0/N	1.0	2.0	3.0	3.3	6.7	10.0	20.0	67	200	Boltzm.
ξ	5.66	2.63	1.71	1.54	0.85	0.68	0.56	0.53	0.53	0.42
ξ_0	0.18	0.22	0.22	0.21	0.18	0.17	0.15	0.15	0.15	0.14

The solution makes it possible to estimate the time t of

the formation of the output distribution of the charger. At $v_0/N \ll 50$ when this distribution is far from stationary, the above time is practically independent of v_0 but is decreasing in inverse proportion to N . E.g. assuming the equality $v_0 = N$, the dependence of t on N can well be approximated with the equation

$$t/s = \frac{10^{11}}{N / \text{m}^{-3}}. \quad (6)$$

The formation time of the stationary distribution in the case of $v_0/N \geq 50$ is independent of N and decreases approximately in inverse proportion to v_0 . $a \approx 1.4$ was found to be the condition of the formation of the stationary distribution by the charging parameter a .

Experimental testing of the charging theory

The idea of experimental testing of the above theory can be described as follows. A symmetric bipolar ionic atmosphere with an adjustable initial ion concentration v_0 is created in an aerosol with maximally monodisperse neutral particles of a known concentration N . The aerosol is given a relaxation time sufficient for the decrease of ion concentration to the natural level, and the charge distribution of aerosol particles at the outlet of the charger is measured. A detailed block-diagram of the experimental set-up is presented in Fig. 1. DOP aerosol from the condensation generator AG arrives at the inlet of the mixer-relaxer M-R with the flow rate \dot{V}_2 through the electric filter EF (for the removal of charged particles). Ions from the corona ionizer CI are flown out by a sonic jet of filtered air flowing around a needle before the nozzle (flow rate \dot{V}_1). A high mixed voltage is applied to the needle point relative to the nozzle from sequentially switched on sources of AC and DC.

Bipolarly ionized air comes into the mixer through the tube T of adjustable length L (for the adjustment of the initial concentration of ions v_0 at the inlet of the mixer). CI, T, and M-R together form the charger with an ionizer that can be switched off.

The aerosol particle concentration N at the inlet to the mixer was determined with a photoelectric counter PEC model AZ-5. Due to the low dynamic range of PEC it was necessary to dilute the aerosol, for this purpose electric dilutors ED)

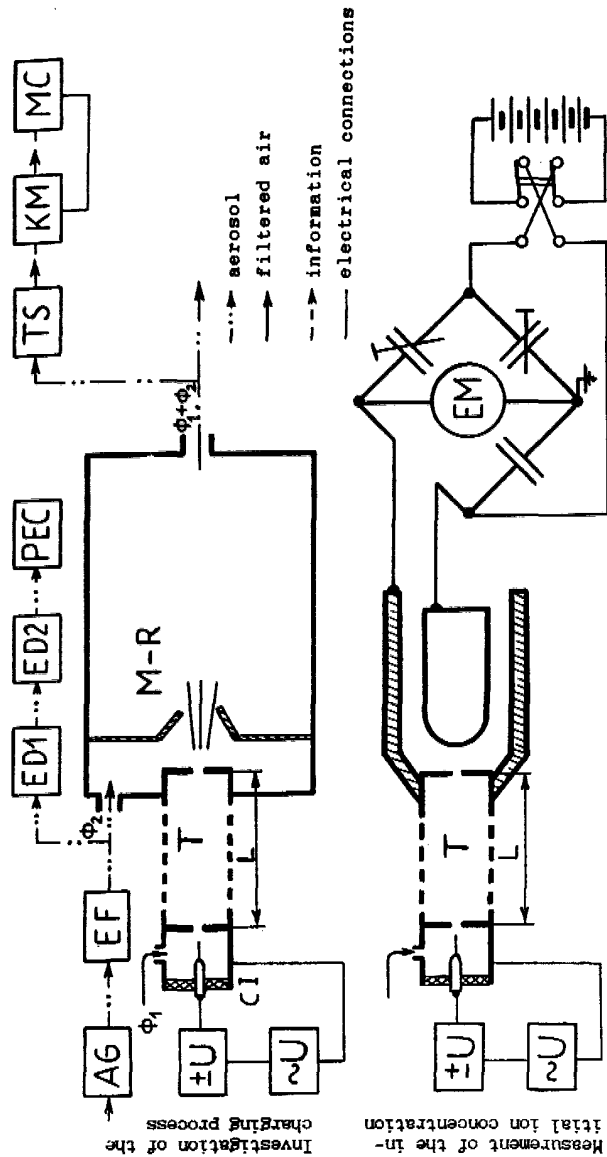


Fig. 1. Diagram of experimental set-up.

and ED2 [6] were used. Charge distributions of the particles were determined with a trajectory spectrometer TS [7]. Photos of the particle tracks were processed with a semi-automatic coordinate measurement device KM [8] operated on-line with an microcomputer MC (model *Elektronika D3-28*).

The device depicted in Fig. 1 (below) was used to determine the initial ion concentration ν_0 in dependence on the length L of the tube T where ion concentrations fall because of their mutual recombination. Bipolarly charged air from the tube T enters the measuring capacitor, in the electric field of the capacitor ions are separated according to their sign and precipitated to the covers. The polarity of the capacitor voltage is commutated and the electrometer EM is used alternately for the measurement of ion currents of both signs on the cover of the capacitor. ν_0 is calculated through the current and the flow rate ϕ_1 . To suppress noise ensuing from the instability of the power source the measuring capacitor was connected into a bridge circuit balanced by AC.

The constructional and regime parameters of the ionizer were selected so that by changing the length L from 0 to 430 mm, the initial concentrations of ions of both signs in M-R (taking into account the dilution by ϕ_2) were adjusted in the limits $(1.0 \cdot 10^{11} - 1.0 \cdot 10^{15}) \text{ m}^{-3}$. The average error of the determination of ν_0 is 15%. The equality $\nu_0^+ = \nu_0^-$ is achieved by the selection of the direct component of the voltage on the point.

The experiments were conducted with DOP aerosol with an average particle radius of $0.6 \mu\text{m}$, the particle concentration in M-R was kept constant: $N = (1.0 \pm 0.5) \cdot 10^{12} \text{ m}^{-3}$. The accuracy of the determination of N is low due to the low precision of PEC (the same PEC was used for the determination of dilution coefficients of ED1 and ED2).

The charge distribution of particles was measured for five values of the ratio ν_0/N . In every case tracks of 200-300 particles were processed. Fig. 2 graphically exemplifies some experimental distributions, as a comparison Fig. 2 presents theoretical curves for similar values of the relation ν_0/N and the curve of the Boltzmann distribution. The shift of the nodes of the experimental curves towards negative charges can be explained by the fact that if $\nu_0^+ = \nu_0^-$, then, due to the inequality of the mobilities of ions of different signs,

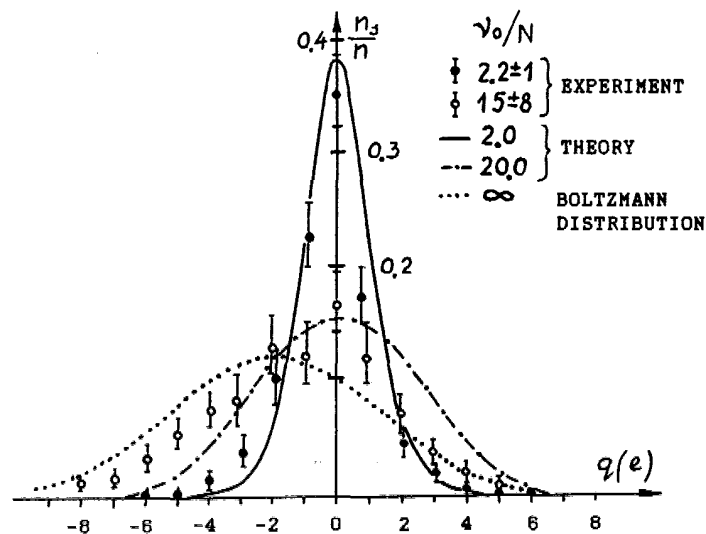


Fig. 2. Comparison of experimental and theoretical distributions. n_j - the number of particles with the charge je , n - the total number of particles.

the probability of a particle catching a negative ion is higher than the respective probability for a positive ion. To simplify the task this is disregarded in equations (4); in the Boltzmann equation [1] it is reflected in the inequality of polar conductivities. If to shift the theoretical curves so that the mode coincides with the mode of the respective experimental distribution, then the experimental points would coincide with the theoretical curves within the confidence limits. Confidence limits of relative frequencies n_j/n are calculated using unsymmetrical estimation formulas.

Conclusions

The satisfactory coincidence of experimental and theoretical distributions makes it possible to use the data in Table 1 for the selection of the operational regime of a charger with an ionizer that can be switched off. For particles with an average radius of $0.6 \mu\text{m}$ the optimum value of the ratio v_0/N can be considered to be 2. The dependence

of the optimum value of this ratio on particle size needs further investigation.

References

1. Кикас Ю.Э., Сузи Р.Э., Тамм Э.И. К теории метода электрического сепарирования аэрозольных частиц // Уч. зап. Тарт. ун-та.- 1982.- Вып. 631.- С. 78-84.
2. Пейль И.А., Тамм Э.И. О получении монодисперсного аэрозоля методом электрического сепарирования // Уч. зап. Тарт. ун-та.- 1984.- Вып. 668.- С. 44-52.
3. Таммет Х.Ф. К технике электрической гранулометрии аэрозолей // Уч. зап. Тарт. ун-та.- 1980.- Вып. 534.- С. 55-79. (See this volume pp. 94-115).
4. Фукс Н.А. О величине зарядов на частицах атмосферных аэроколлоидов // Изв. АН СССР. Сер. геогр. и геофиз. - 1947.- No.4.- С. 341-348.
5. Таммет Х.Ф. Электрические параметры загрязненности воздуха // Уч. зап. Тарт. ун-та.- 1977.- Вып. 443.- С. 48-51.
6. Пейль И.А. Электростатический разбавитель аэрозоля // Уч. зап. Тарт. ун-та.- 1987.- Вып. 755.- С. 120-125.
7. Тамм Э.И., Фишер М.М. Определение размеров и зарядов аэрозольных частиц в пределах радиусов от 0.35 до 1.2 мкм ультрамикроскопическим (траекторным) методом // Уч. зап. Тарт. ун-та.- 1973.- Вып. 320.- С. 108-128.
8. Мирме А.А. и др. Полуавтоматический координатометр // Уч. зап. Тарт. ун-та.- Вып. 479.- С. 132-139.
9. Liu B.Y.H., Pui D.Y.H. A submicron aerosol standard and the primary, absolute calibration of the condensation nuclei counter // J. Coll. Interf. Sci.- 1974.- Vol.47, N 1.- P. 155-171.
10. Scheibel H.G., Forstendörfer J. Generation of monodisperse Ag- and NaCl-aerosols with particle diameters between 2 and 300 nm // J. Aeros. Sci.- 1983.- Vol. 14, N 2.- P. 113-126.

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