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ELECTROSTATIC METHOD OF CALIBRATING PHOTOELECTRIC AEROSOL PARTICLE SIZE METERS

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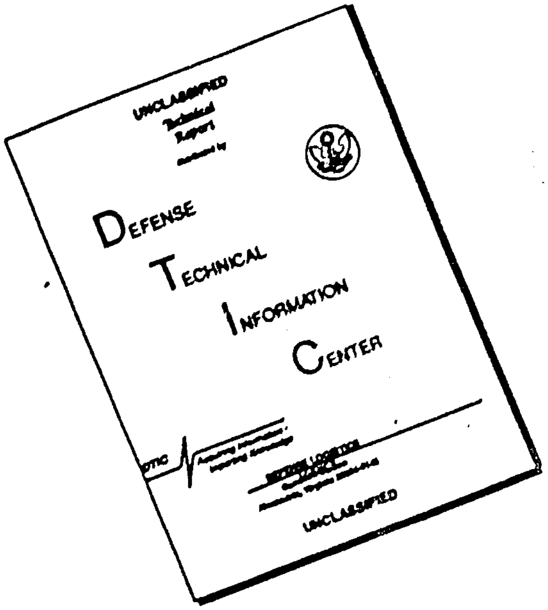

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Visual and photoelectric devices for spectrum determination and aerosol concentration have been devised; however, one of the most complex problems arising during research on aerosol while using these devices is their grading.

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NOTICE

ELECTROSTATIC METHOD OF CALIBRATING PHOTOELECTRIC AEROSOL PARTICLE SIZE METERS .

S.P. Belyaev - A.G. Laktionov

Both in the Soviet Union and abroad, visual and photoelectric devices for spectrum determination and aerosol concentration have been devised. One of the most complex problems arising during research on aerosol while using these devices is their grading. What is particularly difficult is the graduating of instruments from the lowest limit of their applicability ($r=0{,}8 \cdot 10^{-5}$ cm.) up to that limit, above which it is possible to graduate instruments according to the speed of particle fall in the sedimentometers ($r \cdot 3 \div 5 \cdot 10^{-4}$ cm.).

The present paper suggests a method of graduating devices in this very interval of particle size. The known effect of charged particle fall is used for this purpose, as they pass through a flat condenser. At the output of the photoelectric device is usually installed a multichannel amplitude analyser ; in each channel, only signals from a determined fraction of particle size can join. For the purpose of calculations given below, as well as for clarity's sake, a single channel has been selected, in which register all signals with amplitude tension above V_1 (lowest point of discrimination in the given channel) and below V_2 (lowest point of discrimination in the next channel).This permits the isolation out of polidispersed aerosol of a sufficient particle fraction containing radiuses (so far unknown) from r_1 up to r_2 (of course $r_2 > r_1$. Particularly this circumstance, that in the given case, it is possible to observe the change of concentration of particles only in a narrow fraction, thus giving a foundation for the realisation of the method suggested here.

In the condenser (diagr.1) on which plate is applied constant tension Λ enters a flow of polidispersed aerosol with a volume of expenditure in the time unit Q, the concentration of particles, ranging in size from r1 to r2 , equal to N_0 on entry. On exit from condenser, on account of deposit of a part of the charged particles of given sizes, their average concentration flow changes and will become N . The (in 3) expounded idea for graduation consists of the fact that upon gradual increase of tension Π the critical tension $\Pi 2$ is reached, at which time on the condenser plate fall the largest of given fraction of particles with a radius of r2, charged with one elementary charge. Upon further increase of tension concentration N upon exit will not alter, as out of the fraction being observed (r1 + r2) all charged particles fell. On critical tension Π 2, corresponding to the moment of deposit of r2 particles with a single elementary charge, upon known sizes of a condenser placed vertically and the known expenditure volume air through the condenser, as will be shown below, in principle, the determination of r2 is possible.

In order to have a better idea of the possibilities offered by this method, as well as for the evaluation of possible errors, let us find the analytical connection between $\frac{N}{N_o}$ and Π.

In the calculations which are given below, we overlook inertia and particle sedimentation in consideration of small size of particles and the vertically placed condenser.

Let us examine first the qualitative picture of particle deposit on condenser plates. The question is the following : will the given particle fall or not, at a given flow of air on the plate. This depends on the speed of its displacement toward the condenser's plates under the action of electric current (we did not examine particle fall under the action of other energies) and on the initial disposition of particles upon entrance in the condenser.

We will mark (diagr.1) a horizontal speed component (the component which is directed across the flow) through U. For the examined diapason of particle size, the resistance of air to the movement of particles is expressed sufficiently accurately by the Cunningham formula. Therefore, component U can be expressed as follows

$$U = \frac{e\nu\Pi\left(1+\frac{Al}{r}\right)}{6\pi\eta r h}, \qquad (1) \qquad (1)$$

where
e - charge of one electron
ν quantity of elementary charges in the particle ;
A - coefficient depending on the character of reflected gas molecule from the particle surface
l - length of free run of gas molecules ;
h - distance between condenser plates

At the given tension Π ($0 < \Pi < \Pi_2$) there are present in the air such particles as have a size and charge, that upon entry into the condenser, even at a most unfavorable point for fall (for example, for particles positively charged at point A, diagr.1) these particles fall at the very farthest edge of the opposite charged plate (draw.1, point C) . Such particles, at a given tension define a border trajectory.

Particles of a smaller size (at the same charge number) or with a larger charge number (but with the same size), in comparison with the first case , accordingly to the formula will have a greater fall speed and will fall closer to the critical point C (for example, at point D). We will name all this group of particles, whose trajectory is independent of their position on entry end on the surface of the condenser plates, as particles fully capable of falling at a given tension .

Positive particles, which have greater sizes or smaller charge quantities than in the first case, will not fall on the negative plate, if they enter condenser at point A . However, if these particles will enter in the condenser at point B or at the left of point B, then they will fall on the plate of the same tension. The particles will also not fall on the plate, if they get in at the right of point B. The position of point B itself depends on the charge and size of particles and with an increased charge or with the growth of particle size, point B removes itself from point A .

All this group of particles, the question of their fall depending on the initial position at their entrance in the condenser, we will call partly capable of falling. At a tension, infinitely close to zero, apparently, all groups of particles will partly fall.

The flow of particles in the direction of one of the condenser plates is proportional to the area of the plate produced on the speed of particle movement in the direction of the plates and on the concentration of charged particles, in opposition to the plate charge .

If the condenser plates are equal in surface area and if charged particles are biopolar and simetrical, then the overall number of particles size r1 up to r2, partly fall in a unit of time on both plates (tension on them, infinitely close to zero) will be

$$M = \sum_{\nu=1}^{\infty} \int_{r_1}^{r_2} \frac{n_\nu(r)}{2} 2SU(\nu; r)\,dr, \qquad (2)$$

in which n density of distribution by size of particle concentration with charge (both signs) symbols

S - area of one condenser plate

It seems that the flow of falling particles cannot be any bigger than the particle flow entering the condenser. From this, it follows that (after concentration reduction of falling particles in the left and right is not even)

$$Q \geq SU(\nu; r).$$

that is, when with the help of this equation the variable M can be described only on account of the fall of single charge particles. For this case, out of equation (4) we have :

$$M = Q \sum_{\nu=2}^{\infty} N_\nu + Q \int_{r_1}^{\bar{r}} n_1(r)\,dr + S \int_{\bar{r}}^{r_2} n_1(r) U(r) \cdot dr. \qquad (6)$$

The symbol $\bar{r}$ is determined out of Fuchs deduction (6; §26 and 27) about the fact that the distance l_1 (diagr.1) from condenser entry up to the place of falling appears to be the function of average speed of the flow and does not depend on the profile of flow speeds. From there, for the maximum trajectory, one can write down $\frac{L}{\omega} = = \frac{h}{U}$

from there, with the calculation (1) it follows

$$\bar{r} = \frac{C\Pi}{2Q} + \sqrt{\frac{C^2 \Pi^2}{4Q^2} + \frac{CAl\Pi}{Q}}, \qquad (7)$$

where the coefficient $C = \frac{eS}{6\pi\gamma_1 h}$ appears to be the constant for two given conditions and the given condenser.

Inasmuch as $\bar{r}$ in a complex manner depends from Π, according to (6), M also in a complex manner depends on Π.

In order to go over from the quantity of falling particles to the concentration N of particles at exit point of condenser (it is through this very point that we register with a photoelectric device) we will proceed with the assumption that the overall quantity of particles, entering the condenser, is equal to the sum of particles, falling in the condenser and exiting from it. The general amount of particles size r1 up to r2 entering in one time unit into the condenser, will be QN_0 (N_0 – concentration of all particles, including noncharged, size r1 up to r2, that is i.e. $N_0 = \sum_{\nu=0}^{\infty} \int_{r_1}^{r_2} n_\nu(r)\,dr$.

The overall number of particles, coming out of the condenser in one unit of time, QN. Out of the balance of particle number we find that

$$\frac{N}{N_0} = 1 - \frac{M}{N_0 Q}$$

On diagr.2 is brought about a theoretical dependence of the relation $\frac{N}{N_o}$ from tension on condenser (curve 1),

As was already said, close to Π 2 M does not appear to be the linear function Π . If one is to receive a similar graph experimentally then, having determined out of it the symbol Π_1 , by the formula (7) one can easily determine the size of the particle r2, changing Π for Π_2 , and T for

However, as it is observed from the diagram, the practical definition of the symbol Π_1 , brings about certain difficulties, and calculations indicated that in the presence of insignificant oscillations in concentrations upon entry to the condenser , errors are possible in the determination of r2, as the curve

$\frac{N_{11}}{N_o} = f(\ )$ goes over very smoothly in the straight

line $\frac{N_{11}}{N_o}$ = const, (where N_{11} - concentration of noncharged particles). This circumstance appears to be a major shortcoming of the method described in this paper.

Below is described a modification to the method, which allows to increase the exactitude of the determination of particle size, this to a substantial degree .

Let us examine the curve, determined by the equation (4), in the tension interval from $\frac{\Pi}{2}$ up to Π. In this interval the tension of singlecharged particles of aerosol size from r1 up to r2 do not fall entirely ; at the same time double charged particles of the same size fall entirely; therefore, for this case, the equation will look like this

$$M \quad Q \sum_{=2} N_{\cdot} + S \int_{r_1}^{r_2} n_1(r)\, U(r)\, dr. \qquad (9)$$

In the integral equation member (9) the symbol n1 depends on r much less than U on r. The dependence of U from is given by the formula (1) . The dependence of n1 from may be calculated by the formula of stationary distribution of charges on natural aerosols (Boltzman formula) suggested by Fuchs (6) . According to these formulas, when changing r by 20% n1 changes less than 2%, when $r=10^{-5}$ cm. and changes by 8%, when $r=10^{4}$ cm., at that time U changes by 31 and 22% accordingly.

Consequently, in the first approximation one can consider that n1 depend on r. Then, drawing (1) and (5) and integrating (9) , we obtain

$$M = Q \sum N_{\cdot} + C \frac{HN_1}{r_2 - r_1} \left[\ln \frac{r_2}{r_1} + \left(\frac{1}{r_1} - \frac{1}{r_2} \right) Al \right]. \qquad (10;$$

As can be seen from the formula (10), within the limits from $\frac{\Pi_2}{2}$ up to Π, the symbol M and, consequently, correct (8), the symbol of relation $\frac{N}{N_o}$ in linear depend on Π .
Naturally, that linear dependence may occur only in such a case, if $\frac{\Pi_2}{2}$ is less than Π ; Then, the lesser the symbol $\frac{\Pi_2}{2\Pi_1}$, then the larger the area where the linear dependence takes place. In its turn, symbols $\frac{\Pi_2}{2}$ and Π , upon smooth even conditions agree (7), and depend on symbols r_2 & r_1 .

Calculations according to this formula indicate, that the narrower the channel of the registrating installation of the photoelectric meter (that is, the lesser the difference between r2 and r1) the larger the rectilinear area.

For example, let us show, that if monodispersional particles enter the channel (r1 = r2), then the dependence $\frac{N}{N_o}$ = f (11) will have a broken appearance, consisting only of rectilinear areas ; the place of braking will be in points where the tension reaches a critical position for particles with charge amount v=1,2, ..., ∞ .
The very same dependence will represent a complex line, without rectilinear areas, if r2 > 1,62, by r1 = 0;8 . 10^{-5} cm. and r2 > 1,95 r by r =10^{-4} cm.

In the case if r2 = 1,1 r1, then the areas of straights occupy a significant part of the curve. Thus for

$r_1 = 0{,}8\cdot 10^{-5}$ cm [illegible] $\frac{\Pi_2}{2}$, a для r_1 = 10^{-4} cm Π_1 = 1,8 $\frac{\Pi_2}{2}$.
but for

Agreeing with formulae (8) and (10), in the interval from $\frac{\Pi_2}{2}$ up to Π, (diagr.2) the equation of the straight for singlecharge particles will be :

$$\frac{N}{N_0} = 1 - D\Pi\frac{N_1}{N_0} - \frac{\sum_{\nu=2}^{\infty} N_\nu}{N_0}, \qquad (11)$$ (11)

where

$$D = \frac{C}{Q(r_2 - r_1)}\left[\ln\frac{r_2}{r_1} + \left(\frac{1}{r_1} - \frac{1}{r_2}\right)Al\right]. \qquad (12)$$ 12)

Let us find now tension Π_x , upon which the straight, determined by by equation (11) , is crossed with the straight $\frac{N_h}{N_o}$ = const.
Keeping in mind thet

$$\frac{N_h}{N_0} = 1 - \frac{\sum_{\nu=2} N_\nu}{N_0} - \frac{N_1}{N_0}$$ we obtain (13)

$$\Pi_x = \frac{1}{D}.$$

Practically speaking, it is possible to find the point of intersection on the experimental graph with much fewer possibilities for error than tension Π_2 .

If such levels of tension discrimination were set on the amplitude analyser, so that the tension of symbol V1 from particle r1 were higher μ^2 times signal V2 from particle r2, using dependence $V \sim r^{2*}$ the following may be put down :

$$\frac{r_2}{r_1} = \sqrt{\frac{V_2}{V_1}} = \mu. \qquad (14)$$

(14)

Now out of (12), (13), and (14) it is easy to find the symbol r1 and r2

$$r_1 = b + \sqrt{b^2 + \frac{CAl\Pi_x}{\mu Q}} \text{ и } r_2 = \mu r_1, \qquad (15)$$

5)

where

$$b = \frac{C\Pi_x \ln \mu}{2Q(\mu - 1)}. \qquad (16)$$

.5)

This way the operation of determining the size of particles is transfered toward the experimental determination of the character of dependence $\frac{N}{N^\circ}$ from Π

after which on the graph $\frac{N}{N_o} = f(\Pi)$ is easily found, and from there, according to formula (15) and (16) the size of r1 and r2 . The errors which arise from definition r1 and r2 by the given means, are connected with the concentration fluctuations of aerosols upon entry and with fluctuations of the portion of charged and uncharged particles. They also depend on the incline of the right angle, which is determined, in its turn, by the portion of single charge particle and the size of D (D depends on the size of particles and the width of the channel). At concentration oscillations on entry in the condenser within the limits of 10%, the error in determining r1 and r2 does not exceed the limits of the same approximated 10%, if = 1,1 and r1= $0{,}8 \cdot 10^{-5}$ cm., and does not exceed the limits of 12%, if = 1,1 and r1 = 10^{-4} cm.

At error computation, the percentage of charged particles and the quantity of charges on particles, just as earlier, were calculated according to the Bolzman formula. In order to increase the accuracy of the method, three approaches may be recommended :

1) concentration stabilisation of aerosols upon entry into the condenser is indispensable,
2) decrease, inasmuch as it is possible, the width of the

channel and

3) increase the amount of single charge particles.

The latter, in particular, concerns the larger particles, as with size growth of particles, the amount of multicharged particles increases. Therefore, in the case of large particles, it appears expedient to discharge aerosols artificially. Control for determining of single charge particles amount can be obtained through the amount of uncharged particles. Thus, for example (as it must be according to the Bolzman formula) if the number of uncharged particles is no less than 25%, this guarantees a portion of single charged particles of no less than 40% . The tension Π_g changes within the limits of from 6 v. for particles with $r_2=10^{-5}$ cm. up to 150 v. for particles with $r_2=10^{-4}$ cm.

The diagram of the installation, destined to the grading of photoelectric devices by electrostatic means is shown on diagr.3.

On this installation is performed the grading of a photoelectric device of the FICHA-K-O type described in (4). The device of the FICHA-K-O type is based on photoelectric measuring of light intensity, dispersed by one particle in a narrow body (?-telesnii) corner in the direction, close to the direction of light, lighting the particle. The division of pulses, falling from FEU, according to the size of amplitudes, is produced by a five channel amplitude analyser.

For the purpose of graduating devices a specially devised flat condenser was used. It consists of two metal plates, divided by two (ftoroplastovimi ?) gaskets or paddings. The distance between condenser electrodes $h = 0{,}3$ mm., the surface of electrodes $S = 16{,}7$ cm2. , the volume of air through the condenser $Q = 0{,}4$ cm3/sec. Air, as is indicated on diagr.3, is sucked in the device QICHA-K-O from the lower (torts) of the condenser . Suction speed controls, at pressure drop on the entry capillar of the FICHA-K-O device by a needle manometer 4 .

To accomplish the graduation, particles of dust were used, which are found in air in the laboratory (at that time there was no one in the laboratory except the operator). Stability of particle concentration in the air was controled by the measuring of particle concentration passing through the condenser, whose both facings were earthed.

Such aerosol checking is carried out several times (three to five) in each measuring cycle. The first preliminary experiments gave positive results in the graduation of devices, satisfactorily agreeing with curve graduation of Gucer and Rose (7) carried out for much larger particles ($r \; 0{,}3 \cdot 10^{-4}$ cm.)

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Diagr. 1

Trajectories of charged particles in the condenser when aerosol stream passes through it.

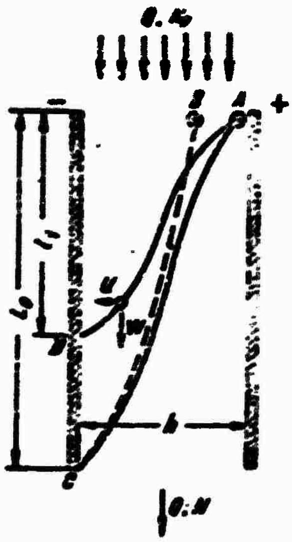

Рис. 1. Траектории заряженных частиц в конденсаторе при протекании через него потока аэрозоля

Diagr.2

Change in concentration of particles on exit out of the condenser depending on applied tension. Curved are made for stationary charge distribution on particles, according to Borsman formula.
Curve I (all indications for it are with stroke) is calculated for measuring particles size
$r1=0,8.10^{-5}$ cm.,
$r2 = 1,3 \cdot 10^{-5}$ cm.

Curve 2 (all indications with two strokes) calculated for particles
$r1= 0,8.10^{-5}$ cm.
$r2 = 0,9.10^{-5}$ cm.

Curve I does not have right angle area, as

see pge 12

diagr.2 cont'ed.

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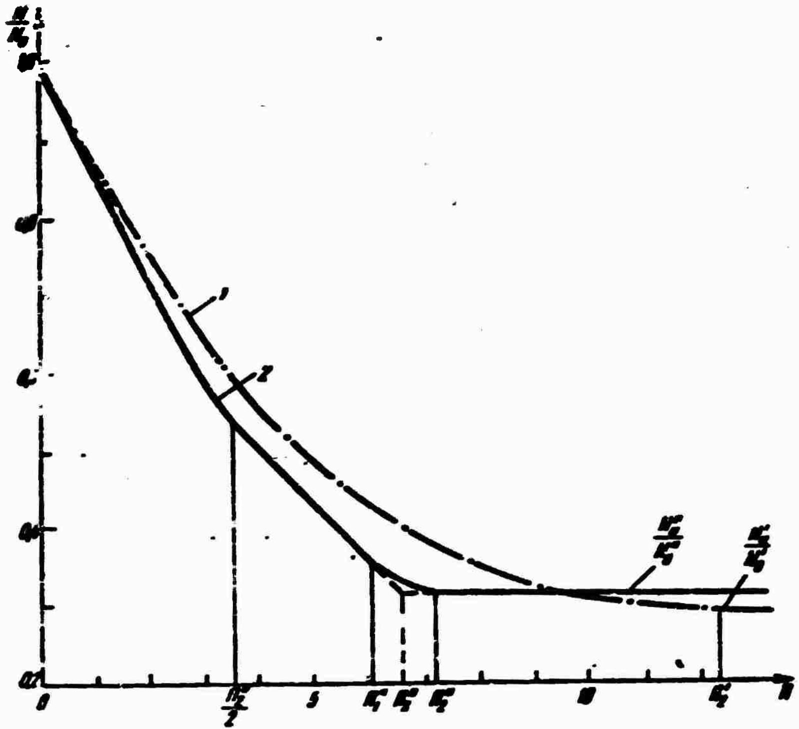

Рис. 2 Изменение концентрации частиц на выходе из конденсатора в зависимости от подаваемого напряжения. Кривые построены для стационарного распределения зарядов на частицах, согласно формуле Больцмана. Кривая 1 (все обозначения для нее с одним штрихом) рассчитана для размеров частиц $r_1=0{,}8\cdot10^{-6}$ см, $r_2=1{,}3\cdot10^{-6}$ см. Кривая 2 (все обозначения с двумя штрихами) рассчитана для частиц $r_1=0{,}8\cdot10^{-6}$ см, $r_2=0{,}9\cdot10^{-6}$ см.

Кривая 1 не имеет прямолинейного участка, так как $П'_1 = П'_2 \approx \frac{П_2}{2}$.

diagr.3

Installation diagram for graduation of photoelectric instruments

1 photoelectric device of FICHA -K-O type
2 electric condenser
3 filter for cleaning air
4 measuring instrument for presure overfall on capillar
5 electronic registering installation
6 air suction system

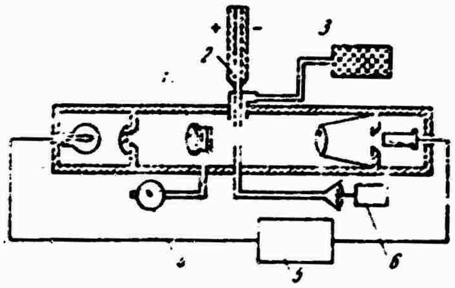

Рис. 3. Схема установки для градуировки фотоэлектрических приборов

1 — фотоэлектрический прибор типа ФИЧА-К-0, 2 — электрический конденсатор, 3 — фильтр для очистки воздуха, 4 — измеритель перепада давления на капилляре, 5 — электронная регистрирующая установка, 6 — система отсоса воздуха.