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Cluster diameter measurements using an electric mobility spectrometer



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ABSTRACT

The geometric standard deviation, σ_g , of monodispersed polystyrene particles employed in the calibration of aerosol counters can be affected by the fraction of clusters generated by liquid atomization.

Graphical analysis of the continuous particle size distribution obtained by the light-scattering method, revealed the peaks corresponding to the different cluster multiplicities.

The cluster diameter values have been confirmed by an electric mobility analyzer.

Aerodynamic diameters, calculated from the relationship $X_k = \frac{1}{K}$ in terms of the relative diameter $f_N = \frac{D_N}{D_1}$ and f_n , introducing the Stöber correction factor, are given.

The resolution of peaks calculated from the particle size distribution, obtained by light or laser scattering instruments, must account for the formation of clusters depending on the aqueous concentration and the water drop diameter.

INTRODUCTION

Errors in aerosol size distribution measurements can arise from agglomerated particles forming clusters which increase the geometric standard deviation of the distribution.

Liquid atomization is a standard way of generating suspended particles in air which are employed in problems involving aerosols. At high liquid concentrations, the fraction of agglomerated particles becomes important and the standard deviation of the aerosol distribution increases correspondingly.

Monodispersed polystyrene latex particles have been used in the calibration of the Climet C 201 counter (from Technworld Inc., Sunnyvale, California, USA)⁽¹⁾. The instrument employs a light-scattering method to reveal the concentration and particles distribution between 0.3 and 10 μ . Light, scattered by a particle, is focused on a photomultiplier. The pulse height, proportional to the particle size, enters a multichannel analyzer. The counting system was calibrated using polystyrene particles suspended in air to determine the performances of the instrument, the peak resolution and the calibration curve: particle diameter/channel number.

During the calibration procedure, the peaks corresponding to 0.807 and 1.1 μ diameter monodispersed particles, were found to be associated with continuous distribution arising from agglomerated particles (Fig. 1). After graphical analysis the diameters corresponding to the different multiplicity have been evaluated using the calibration curve.

Previous measurements of the aerodynamic cluster diameter (defined as that of a sphere of the same density and settling velocity

as the cluster) have been carried out using a preliminary particle sampling device such as a centrifuge ^{(2) (3)} or electrostatic analyzer ^{(4) (5) (6)} and visually in an electron microscope. It was deduced that the diameter D_N of a cluster containing N spheres should be related to the diameter D_1 of a single sphere by the expression:

$$(\sqrt[4]{N}) D_1 \leq D_N \leq (\sqrt[3]{N}) D_1 \quad [1]$$

The aim of this report is to calculate the aerodynamic diameter of particle aggregates by analyzing the deposition patterns obtained using a parallel plate mobility analyzer and to confirm the calculated cluster diameters obtained by the light-scattering method.

EXPERIMENTAL PROCEDURE

A high resolution (2.5%) electric mobility spectrometer previously described ⁽⁹⁾ was employed in the measurements of the electric mobility of particles. Aerosol particles (0.807 μ) purified by repeated centrifugating, were generated by passing pure compressed N_2 through a water suspension of monodispersed polystyrene latex particles. The subkinetic, electrically charged, aerosol flow (45-50 ml.min⁻¹) enters the center of the spectrometer midway between two electrodes maintained at a potential of 10 kV (+ 5 kV). The aerosol deposition patterns are analyzed by a photoscanner device. The signal from a photomultiplier enters a fast pen recorder, yielding the diagram shown in Fig. 2. This diagram is a representative deposition of 0.807 μ monodispersed aerosol particles in which the principal peaks correspond to the multicharged single particles.

To eliminate the influence of the experimental conditions on the deposition, the pattern distances on the plates have been normalized with respect to charge one for a singlet considered at 100% of the deposition distance.

The aerodynamic diameters of multiplets have been calculated from the peaks included between the aerosol entrance slit and the first charge carried by a single particle in the diagram of Fig. 2 and the relationships [2] [3]. For each deposition the plot of Fig. 3 and the cluster diameters, corresponding to the different multiplicity, have been deduced from at least

8 values for doublets carrying 2-3-5-6-7-9-10-11
electric charges

8 values for triplets carrying 3-4-6-7-8-9-12-14
electric charges

5 values for quadruplets carrying 4-5-6-9-11
electric charges

The results are compared in Tables I, II and III.

Microscopic pattern examination has been carried out to ascertain the configuration of the aggregates. The plates were covered with very thin plastic strip. After the deposition of the particles, the strip was cut and placed on glass slides.

DISCUSSION AND CONCLUSIONS

When electric forces are applied to a charged particle entering the spectrometer, the deposition distance, X_k (cm), from the entrance, is inversely proportional to the electric mobility ($\text{cm} \cdot \text{s}^{-1} / \text{V} \cdot \text{cm}^{-1}$)

of the particle:

$$X_k = \frac{i}{K} \quad [2]$$

when

$$K = \frac{n}{3\pi \eta D} \frac{e}{300} c \quad [3]$$

or

$$X_k = \frac{i}{n} \quad [4]$$

where

n = elementary charge unit,

e = elementary electric charge ($= 4.8 \cdot 10^{-10}$ e.s.u.),

η = N_2 viscosity ($= 1.75 \cdot 10^{-4}$ poise),

D = particle diameter ($= 8.07 \cdot 10^{-5}$ cm),

C = Cunningham slip factor ($C = 1 + 0.86 \frac{\lambda.2}{D} = 1.198$).

The pattern analyzer and the relationship [4] determine the peaks corresponding to the cluster multiplicity carrying n_i elementary charges without ambiguity. The diameters, deduced from the calibration curve

$$\log K = f(\log X_k)$$

of Fig. 4, have a deviation from the mean of $\pm 0.5\%$.

As observed in the plot Fig. 3, microscopic examination confirmed a deposition at the same distance for clusters having an equal mobility. The high relative abundance for 3rd, 6th and 9th charge corresponding to a single particle, has been produced by the simultaneous deposition of clusters having the same mobility.

The diagram of Fig. 2 and the observed particles give no indication of vertical doublets ⁽⁶⁾.

Three and four particles were closely packed in triangles, tetrahedrons and squares. Few particles presented the i or y configura-

tion, showing a general tendency to occupy a minimum volume. The same mobility was observed for the different configurations of agglomerated particles.

The cluster diameter values calculated from the mobility analyzer are close to those of the calculated clusters responsible for the continuous distribution observed during the Climet calibration when 0.807μ polystyrene latex was generated by atomization.

The diameter values calculated by the two methods of analysis and the relative diameters $f_N = \frac{D_N}{D_1}$ are listed in the Table I.

As previously reported, different values of relative diameter f_N can be obtained when the particle is moving either in a gravitational or an electric field ⁽⁴⁾. Table II is a comparison of f_N results with others previously obtained.

If the diameters deduced from the electric mobility spectrometer are corrected for the Stober factor ⁽¹⁰⁾, then the relative diameters f_n are in good agreement with those measured by a gravitational field (see Table III), which means that the cluster aerodynamic diameter, calculated from the electric mobility, cannot be taken as that of a sphere and a shape factor must be introduced to account for this difference.

The continuous distribution obtained by the light-scattering instrument, appears clearly when the single particle diameter is $> 0.5 \mu$. At lower diameters the cluster size distribution is masked by the tail of the principal peak, increasing the geometric standard deviation σ_g .

It follows that for instruments employing the light or laser-scattering method, the resolution deduced from the size distribution

of particles in range $0.3 - 0.5 \mu$ in diameter, must account for the cluster fraction from atomization, proportional to the aqueous concentration and to the water drop diameter.

TABLE I - Comparison of Cluster Diameters and f_N values
evaluated by 1) = light-scattering and
2) = electric mobility distribution

No. of spheres in clusters	(1)		(2)	
	$\phi(\mu)$	f_N	$\phi(\mu)$	f_N
2	1.069	1.32	1.054	1.31
3	1.328	1.64	1.315	1.63
4			1.508	1.87

TABLE II - Comparison of f_N Values

No. of spheres in cl.	1	2	3		4	5	this investigation
			aver.	max.			
2					1.43		
2	1.41	1.31	1.27	1.37	1.30	1.263	1.31
3	1.67	1.55	1.47	1.70	1.58	1.454	1.63
4	1.85	1.80	1.61	1.84	1.79	1.593	1.87
5	2.03	2.00			1.93	1.710	
6					2.07	1.836	
7					2.22		
8					2.31		
9					2.41		
10					2.53		

1 = Stöber et al. (1970)

2 = Megaw-Weills, (1970)

3 = Wajsfelner et al. (1970)

4 = Giacomelli Maltoni et al. (1973)

5 = Heyder- Porstendörfer (1974)

TABLE III - Comparison of f_n values.

	1	2	3	4	5	6	7	8	9	10	11
Diam. of unit sphere (cm)	0.12	0.159	$8.8 \cdot 10^{-6}$	0.1 to 0.213	$5.4 \cdot 10^{-5}$ and $7.9 \cdot 10^{-5}$	10^{-5} to $1.15 \cdot 10^{-4}$	3 to 8 10^{-5}	$0.234 \cdot 10^{-4}$	$0.5 \cdot 10^{-4}$	0.488 to $0.727 \cdot 10^{-4}$	$0.807 \cdot 10^{-4}$
No. of spheres in cluster								av.	max.		
2											
2	1.17	1.19	1.18	1.20	1.18	1.23	1.19	1.25	1.21	1.167	1.21
3	1.28	1.28	1.32	1.34	1.33	1.39	1.34	1.43	1.33	1.319	1.31
4		1.41		1.45	1.47	1.49	1.47	1.58	1.47	1.460	1.41
5		1.48	1.52	1.56	1.53	1.58	1.57			1.572	
6	1.54			1.64	1.66		1.68			1.696	
7							1.75				
8							1.81				
9							1.89				
10							1.94				

- 1 = Kunkel (1948): glued glass clusters falling in oil;
- 2 = Mesaw (1964): magnetized steel clusters falling in glycerol;
- 3 = Mesaw and Wiffer (1966): polystyrene clusters diffusing in air;
- 4 = Stöber (1969): magnetized steel clusters falling in syrup;
- 5 = Stöber (1969): polystyrene clusters centrifuged from air;
- 6 = Mesaw and Wells (1970): singly charged clusters in an electric field;
- 7 = Stöber et al. (1970): polystyrene clusters centrifuged from air;
- 8 = Wajsfelner et al. (1970): multicharged clusters in an electric field;
- 9 = Giacomelli Maltoni et al. (1973): singly charged clusters in an electric field;
- 10 = Heyder-Forstendörfer: polystyrene clusters centrifuged from air;
- 11 = this investigation: multicharged clusters in an electric field.

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LIST OF FIGURE CAPTIONS

Fig. 1 : Size Distribution by Light-Scattering

a) 0.807μ

b) 1.1μ

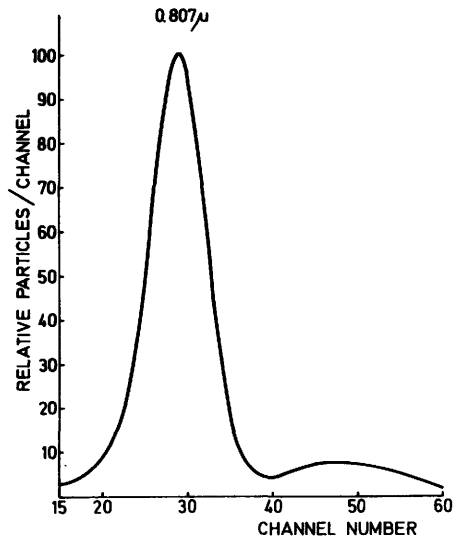
————— : room temperature

----- : heated stream

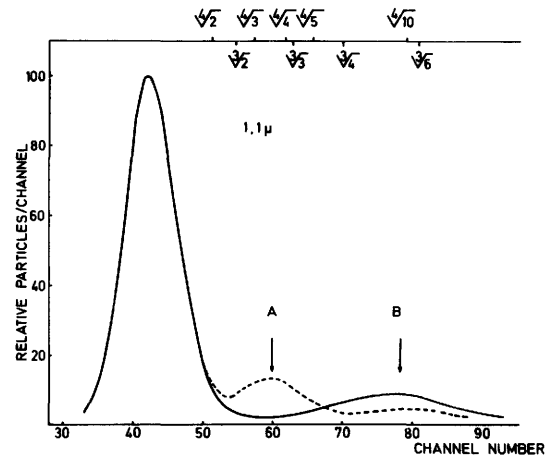
Fig. 2 : Relative Deposition Distances of 0.807μ Polystyrene
Particles - Particles Multiplicity and Elementary
Charge of Clusters are Indicated

Fig. 3 : Plot of $1/n$ versus Relative Distance $(X_k)_{rel}$ for
Particles Multiplicity

Fig. 4 : Plot of $\log K$ (electric mobility) versus $\log (X_k)_{rel}$



a)



b)

FIG. 1

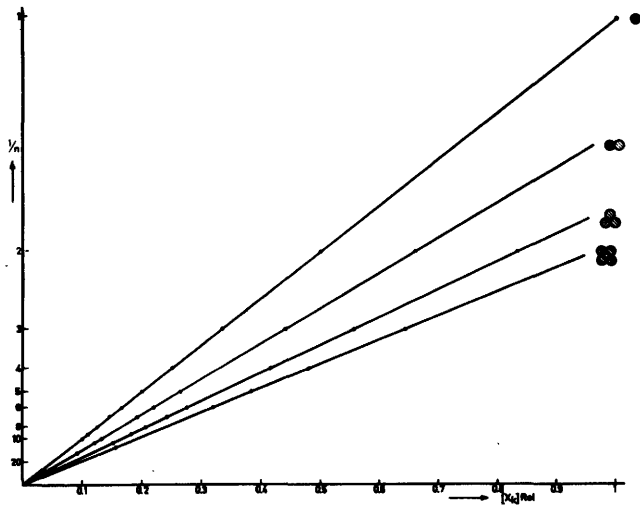


FIG. 3

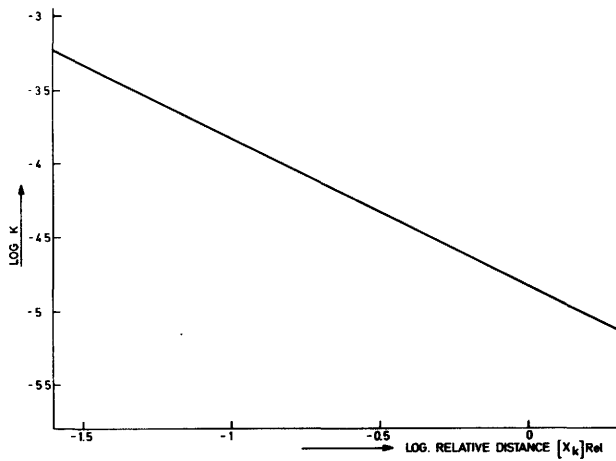


FIG. 4

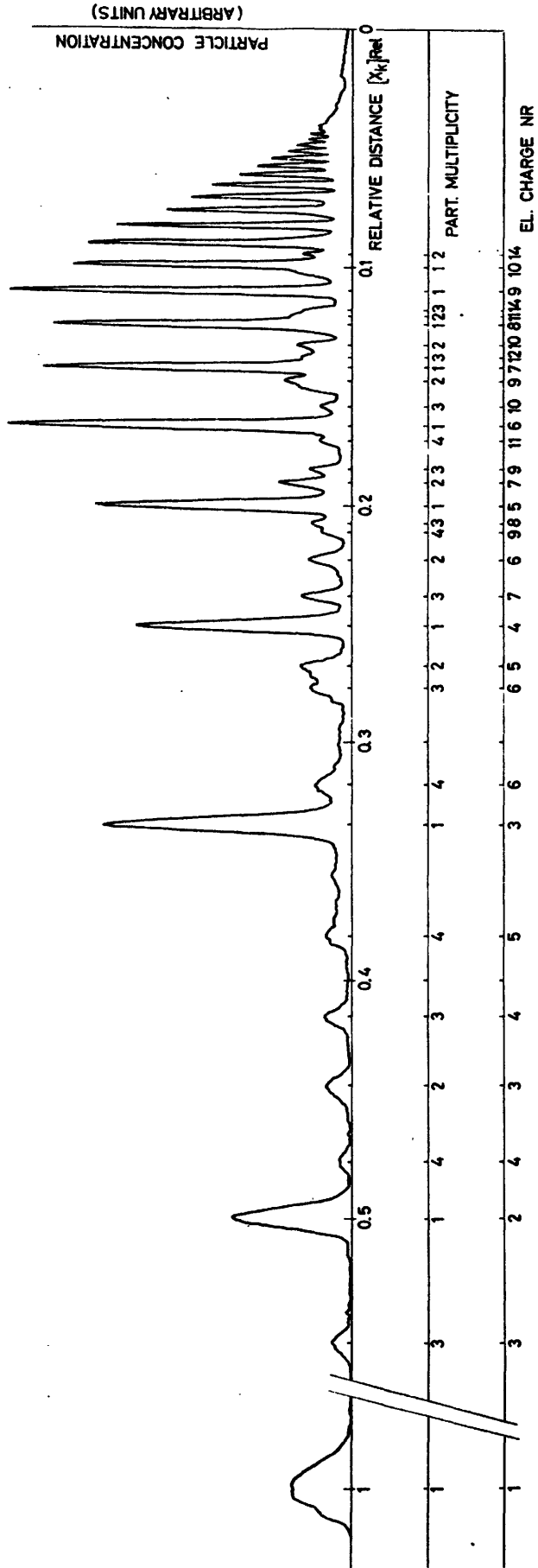


FIG. 2

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