Reports/ 8

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: 23 March 1974

Project Title: Surface Science and Technology

Project No: G-33-518

Principal Investigator Dr. Robert A. Pierotti

Sponsor: National Science Foundation

Agreement Period: From February 15, 1974 Until July 31, 1977

Type Agreement: Grant No. GZ-2896

Amount:
$ 75,000 NSF Funds -42 mos (G-33-518)
50,301 GIT Contribution - 42 mos. (G-33-211)
$125,301 TOTAL (42 mos.)

Reports Required:
Interim Technical Reports (At least annually)
Final Substantive Reports

Sponsor Contact Person (s):

Mr. Wilbur W. Bolton, Jr.
Grants Officer
National Science Foundation
Washington, D. C. 20550

Assigned to: Chemistry

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RA-3 (6-71)

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: August 20, 1981

Project Title: Surface Science and Technology

Project No: G-33-518

Project Director: Dr. R. A. Pierotti

Sponsor: National Science Foundation

Effective Termination Date: 7/31/78

Clearance of Accounting Charges: 7/31/81

Grant/Contract Closeout Actions Remaining:

- _ Final Invoice and Closing Documents
- x Final Fiscal Report FCTR
- x Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
- _ Other ______

Assigned to: Chemistry (School/~~Laboratory~~)

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Other: ______

G-33-518

INTERIM TECHNICAL REPORT

1. TITLE OF GRANT: Surface Science and Technology

2. NSF GRANT NUMBER: GZ-2896

3. NSF PROGRAM: Alternates in Higher Education

4. ORGANIZATION: Georgia Institute of Technology

   ADDRESS: CITY Atlanta STATE Georgia ZIP 30332

5. DIRECTOR: Robert A. Pierotti

   DEPARTMENT: Chemistry

   INSTITUTION: Georgia Institute of Technology

6. PERIOD COVERED BY REPORT: 15 February 1974 to 30 June 1975

7. SIGNATURE OF PROGRAM DIRECTOR: ____________________

   DATE: 15 July 1975

Interim Technical Report #1

Surface Science and Technology

NSF Grant GZ-2896

The grant entitled "Surface Science and Technology" started in February 1974. Although the first technical report was due one-year therefrom, it seemed more reasonable to make this report on a fiscal basis since the grant terminates at the end of June 1977.

New Courses Developed

While the grant offically started in February 1974, the Georgia Institute of Technology provided support from the inital date of our proposal in 1973. The present report therefore covers a period from 1 July 1973 to 1 July 1975. During this period, the following new courses were developed:

1.	Chemistry 6451	Surface Equilibria
2.	Chemical Engineering/ Metallurgy 6087	Heterogeneous Catalysis
3.	Physics 6235	Physics of Surfaces
4.	Chemistry/Chemical Engineering/Physics 6753	Surface Science Laboratory

In addition to those courses newly developed, several other courses have been suitably adapted for this program. These are:

5.	Chemistry 6230	Electrochemistry
6.	Chemical Engineering 6610	Aerosol Technology
7.	Chemical Engineering 6613	Fine Particle Technology
8.	Chemical Engineering/ Textiles 7750	Surface and Solution Properties of Polymers

Attachment I contains the course descriptions for the above courses as given in the 1974-75 General Catalog of the Georgia Institute of Technology.

The Surface Science Laboratory Course

Of particular importance among the above mentioned courses is the new Surface Science Laboratory. Although this course changes in detail with the particular faculty involved and the interests of the students, it is basically made up of essentially 8 to 10 experiments in surface chemistry, physics or technology. These experiments are carried out under the direct supervision of a faculty member using research instrumentation. Each experiment lasts about one week and includes approximately three hours of lecture time and eighteen hours of laboratory time. Attachment II gives the laboratory schedule for this summer quarter and indicates that the students go from laboratory to laboratory as determined by the location of the faculty and instrumentation. Attachment III contains a listing of several of the experiments performed in the SST laboratory, while Attachment IV contains a typical student report on one of these experiments.

The Masters Program in Surface Science and Technology

The program, as far as the development of advanced materials is concerned, must thus far be judged a success since both courses and larobatory experiments in Surface Science and Technology have been developed. Of more direct concern is the success of the graduate program in Surface Science and Technology. The number of students having received masters degrees in the program now stands at three. Two more students completed all the courses in the program, but already had M.S. degrees. The individual course including the laboratory have been attended by more students than those who have obtained degrees.

A total of five students have completed the laboratory course and four are presently enrolled. The individual courses have had enrollments of anywhere from 5 to 20 students each time they have been offered

The program as currently established requires a student take 50 quarter hours of course work including at least 32 quarter hours in the students major field. A student starting in the fall quarter can complete all of the requirements and receive a Masters degree in Chemistry, Chemical Engineering or Physics at the end of summer quarter. See Attachment V for the course schedule for the Masters program in Surface Science and Technology as currently offered at Georgia Tech.

Comments on the Program

The program as described is an academically difficult one. The students who have thus far completed the program have been among the best students currently enrolled in their departments. Since these students have usually required financial support, they have been teaching assistants carrying a full teaching load as well as an extra heavy academic load. The single most significant additional aid that NSF could have provided in the establishment of a new academic program, would be to include two or three fellowships or traineeships per year. This was specifically deleted from our original proposal, but I would urge NSF in making future grants of this type to provide such traineeships. These traineeships would guarantee the program an initial core of students of high calibre during the formative years of the program. We have been somewhat fortunate thus far, but the uncertainity of students in the program has weakened our efforts. The question, at this early point in the program, of whether a course would be offered makes course preparation and laboratory hectic and results in less enthusiasm among the faculty and students.

The faculty involved in the program has changed somewhat since the initial proposal. Dr. Bruce Davis of the School of Chemistry left Georgia Tech for a position in industry. Dr. Pierotti developed and taught those courses originally planned by Dr. Davis. Dr. John Muzzy from the School of Chemical Engineering became deeply involved with the development of Polymer Science program and he dropped out of the present program. Dr. Helen Grenga from the School of Chemical Engineering (Department of Metallurgy) has replaced Dr. Muzzy and in addition has now developed a new course and experiments in catalysis.

The second interim report will be prepared in July 1976 and will emphasize the source of the students, their progress in the program and in the laboratory and their employment decisions upon completion of the program.

The final report will be due in July 1977 and will provide the details of the courses develped, the laboratory experiments designed and the developed and an assessment of the future of the program including a cost effectiveness analysis.

Attachment #1

1. Chemistry 6451. Surface Equilibria
3-0-3.

Classical and statistical thermodynamics of surface systems, intermolecular forces at the gas-solid interface, adsorption phenomena and capillarity.

2. Chemical Engineering/Metallurgy 6087. Heterogeneous Catalysis
3-0-3. Prerequisite: consent of department.

Physical chemistry of surfaces; thermodynamics, kinetics and mechanisms of chemisorption and surface reactions; industrial catalysts.

3. Physics 6235. Physics of Surfaces
3-6-5.

Fundamentals of physical method for studying the structure, composition, vibrational and electronic properties of solid surfaces.

4. Chemistry/Chemical Engineering/Physics 6753. Surface Science Laboratory
3-18-9. Prerequisite: consent of department.

A highly specialized laboratory course using modern analytical and research instrumentation to characterize and study the surface properties of materials.

5. Chemistry 6230. Electrochemistry
3-0-3. Prerequisite: consent of department.

A study of electrochemical instrumentation, the thermodynamics, structure, adsorption of the electrical double layer and the kinetics of simple and complex electrode processes.

6. Chemical Engineering 6610. Aerosol Technology
3-0-3. Prerequisite: consent of school.

Presents basic concepts describing the behavior of dispersed particles. Includes generation, sampling and size analyses, diffusion, coagulation, settling, kinetics and dynamics, electrostatic and optical properties.

7. Chemical Engineering 6613. Technology of Fine Particles
3-0-3. Prerequisite: Ch.E. 3305 or consent of school.

An examination of the properties of finely divided materials. Size, surface, pores are treated in relation to reactivity, adsorptivity, catalytic behavior and process engineering operations.

Attachment #1 (continue)

8. Chemical Engineering 7750. Surface and Solution Properties of Polymers
3-0-3. Prerequisite: consent of school.

Study of plasticized polymers, solutions and colloids: sorption, polymer characterization, interfacial phenomena and coagulation using thermodynamics, statistical mechanics, information and fluctuation theories and relaxation methods. Also taught as Textile 7750.

Attachment II

Surface Science and Technology Program
Schedule for Summer 1975

Days	Dates	Time	Place	Instructor (Office)	Topics
F	20 June	1:00 PM	Chem.	Pierotti (1-27)	Organizational Meeting
MTW	23,24,25 June	9-6	Ch.E.	Orr (325)	Film Balance (Pressure-Area Relations) Mercury Porosimetry
M	30 June 1,2 July	9-6	Ch.E.	Orr (325)	Surface Area Measurements Electrophoresis
MTW	7,8,9 July	9-6	Ch.E.	Grenga (226)	Catalysis and Surface Energy
MTW	14,15,16 July	9-6	Ch.E.	Grenga (226)	Anisotropy
MTW	21,22,23 July	9-6	Phys.	Scheibner (327)	Low Energy Electron Diffraction using Laser Simulation Techniques
MTW	28,29,30 July	9-6	Phys.	Scheibner (327)	Auger Spectroscopy & Surface Chemical Analysis
MTW	4,5,6 Aug.	9-6	Chem.	Pierotti (1-27)	Adsorption Thermodynamics Gas Solid Interactions using Chromatographic Techniques
MTW	11,12,13 Aug.	9-6	Chem.	Pierotti (1-27)	Contact Angle Studies
MTW	18,19,20 Aug.	9-6	Chem.	Sturrock (1-94)	Electrode Processes (Kinetics of Electron Exchange)
MTW	25,26,26 Aug.	9-6	Chem.	Sturrock (1-94)	Chronocoulometry

This course is set-up to include one hour of lecture and six hours of lab at each meeting.

Attachment III

Listing of Experiments Designed and Performed in the Surface Science and Technology Laboratory

1. Surface Area by Low Temperature Adsorption Measurements.

2. Pore Size Analysis by High Pressure Mercury Penetration.

3. Zeta Potential by Mass Transport Measurements.

4. Molecular Cross-Section by Film Balance Measurements.

5. Adsorption Thermodynamics and Gas-Solid Interactions from High Temperature Adsorption and Gas Chromotography.

6. Surface Energies and Surface Tensions at the Solid-Liquid Interface from Contact Angle Measurements.

7. Surface Energy Anisotropy of Tungsten from Field-Ion Microscopy Studies.

8. The Surface Preparation and Orientation of a Copper Single Crystal Using the Back Reflection Lane Technique.

9. The Characterization of a Metal Surface using Auger Spectroscopy, Low Energy Diffraction, Electron Microprobe Analysis and Scanning Transmission Electron Microscopy.

10. The Generation, Collection and Characterization of NaCl Aerosols using Electrostatic Precipitation, Cylindrical Aerosol Spectrometer and by Light Scattering Techniques.

11. The Kinetics of Electrode Reactions using DC Polarography and Potential Step Techniques.

Attachment VI

A Student Report from the Surface Science and Technology Laboratory

Mass Distribution Analysis of a Sodium Chloride Aerosol With a Cylinder-Type Spectrometer.

Ricardo Reich
Surface Science and Technology Lab.

1.- Purpose.-

The present experiment was conducted to obtain a mass distribution analysis of a sodium chloride aerosol, generated with two different kinds of nebulizers, by means of a cylindrical-type aerosol spectrometer.

2.- Equipment.-

2.1.- Aerosol generation.-

The aerosol used for this analysis was generated from an aqueous solution of sodium chloride and uranine as a tracer, the concentration being 0.9% weight in NaCl and 0.1% weight in uranine, i.e. 1% weight in solids. Two kinds of nebulizers were used for this purpose: a No.40 DeVilbiss glass generator and a Puritan nebulizer.

The gas flow rate was 14 liter/min (20 psig) and the aerosols were dried by mixing with 25 liter/min of dry air which had been passed through a Millipore filter. The drying gas and aerosol were mixed in a 600 cm3 glass tube, with baffles, prior to entering the aerosol spectrometer. The concentration of the aerosols after the glass tube were determined as 110 mg/m3 for the DeVilbiss and 14 mg/m3 for the Puritan nebulizer.

2.2.- Aerosol spectrometer.-

A cylindrical-type aerosol spectrometer of simple design was used in the present analysis. The instrument, designed and constructed in the School of Chemical Engineering, Georgia Institute of Technology, is based on a modification of a cylindrical centrifuge developed by Hochrainer[1]. The aerosol in introduced through a cylindrical hole of 1 mm diameter located midway between the top and the bottom of the flow channel. If the size distribution of the analyzed aerosol is monodispersed the particles are deposited as a discrete "dot" on the foil lining on the outer wall of the annular channel; if it is not monodispersed, as in this case, the particles are deposited as a continuous band. A complete description of the centrifuge, design details and calibration results obtained with an aqeous suspension of polystyrene latex spheres can be obtained elsewhere[2]. Figure 1 in the Appendix contains such calibration results for the conditions of the present experiment.

Aerosol was introduced into the centrifuge through the central bore by inserting a lance into it. A black paper strip was inserted in the outer wall of the centrifuge and, once the aerosol was deposited on it, divided into smaller strips, introduced in distilled water to dissolve the deposits, and analyzed for uranine with a Model 111 Fluorometer, manufactured by G.K. Turner Associates. The fluorometer was calibrated against sodium chloride plus uranine aqueous solutions of known concentration. The calibration curve is given in Figure 2 in the Appendix. The centrifuge speed was measured with a General Radio Strobotac, Type 1538-A, strobe light.

3.- Theory.-

3.1.- Log-normal distribution.-

A particle size distribution is commonly treated by dividing a sample into a number of distinct size classes. In the present case the aerosol deposited on the strip of black paper constitutes the sample; the paper is then divided into strips of known size constituting distinct size classes(mass of particles). The amount of mass in each strip then corresponds to the frecuency or the amount of particles in that size class.

This grouped data can be represented graphically in different ways. A size class(mass particle diameter) versus frecuency plot is called a histogram. If the histogram is normalized; i.e. a cumulative percentage frecuency versus particle size interval plot, then it represents a step-like depiction of the particle size distribution or probability density, C(D), where

$$C(D) = d\,F(D)/d\,D$$

F(D) = cumulative fraction of particles with diameters less than size D

D = particle diameter

One mathematical function that has proved useful as a probability density, C(D), for particle sizing is the log-normal function, which is defined as a distribution of sizes whose logarithms are normally distributed, and is given linearly by the following relation

$$C(D) = \frac{1}{D\sqrt{2\pi}\,\ln\sigma}\, e^{-\frac{(\ln D - \ln CMD)^2}{2(\ln\sigma)^2}} \qquad 0 < D < \infty$$

where,

σ = geometric standard deviation of the distribution

CMD = median diameter or geometric mean of the distribution.

Both CMD and σ can be obtained from appropiate algebraic expressions[3] or directly from a logarithmic-probability plot.of cumulative percentage frecuency versus particle size[4]. For a log-normal distribution (a straight line in log-probability paper) the median diameter coincides with the geometric mean diameter. Thus, the mass median diameter is that diameter for which 50% of the particles(mass) are smaller.

4.- Results.-

The results of the present analysis are shown in Table 1 for the DeVilbiss nebulizer. Results for the Puritan generator were not obtained due to negligible deposition of particles on the centrifuge paper strip. The few experimental data obtained are given in Table 2.

5.- Discussion.-

Count geometric mean#	= 0.24 microns
Mass median diameter (Hatch&Choate eqn)	= 0.45 microns
Mass median diameter (this analysis)	= 0.69 microns

Given in separate report.

The mass median diameter obtained in this analysis is quiet larger than the one obtained from a direct count of particles after electrostatic precipitation of the aerosol on a grid. In addition, this last result does not consider a considerable amount of particles smaller than about 0.12 microns which could not been sized. In practice this will result in an even smaller value for the median diameter. Unfortunately I do not find a reasonable explanation for this large difference.

Table 1
Particle mass distribution

Aerosol generation: De Vilbiss nebulizer
Centrifuge conditions: 10000 r.p.m. for 30 minutes

Sedimentation distance, [cm] group size	(higher limit) Aerodynamic diameter, [μM] Fig. 1	Fluorometer reading x 30	NaCl [μg] [Fig 2]
0 - 0.4	2.1 *	83	7.2
0.5 - 0.8	1.38	54	4.3
0.9 - 1.2	1.1	40	2.9
1.3 - 1.6	0.93	46	3.6
1.7 - 2.0	0.81	40	2.9
2.1 - 2.4	0.73 *	33	2.3
2.5 - 2.8	0.67 *	28	1.9
2.9 - 3.2	0.62 *	35	2.5
3.3 - 3.6	0.58 *	16	0.95
3.7 - 4.0	0.55 *	34	2.4
			30.95

* extrapolation

Aerodynamic diameter, [μM]	NaCl [μg] f_i	Cumulative f_i'	% f_i'
2.1	7.2	7.2	23.3
1.38	4.3	11.5	37.2
1.1	2.9	14.4	46.5
0.93	3.6	18.0	58.2
0.81	2.9	20.9	67.5
0.73	2.3	23.2	75.0
0.67	1.9	25.1	81.1
0.62	2.5	27.6	89.2
0.58	0.95	28.55	92.2
0.55	2.4	30.95	100.0

Assuming, from Fig. 3, that the distribution is normal

Mass median diameter (aerodynamic) ~ 1 [μM]

From Fig. 4 ~ 1.04 [μM]

The particle mass median diameter is given by[5]

$$D_{gn} = \frac{D_{ma}}{\rho_p^{1/2}} \cong \frac{1.04}{\sqrt{2.3}} = \frac{1.04}{1.517} = 0.69 \, [\mu m]$$

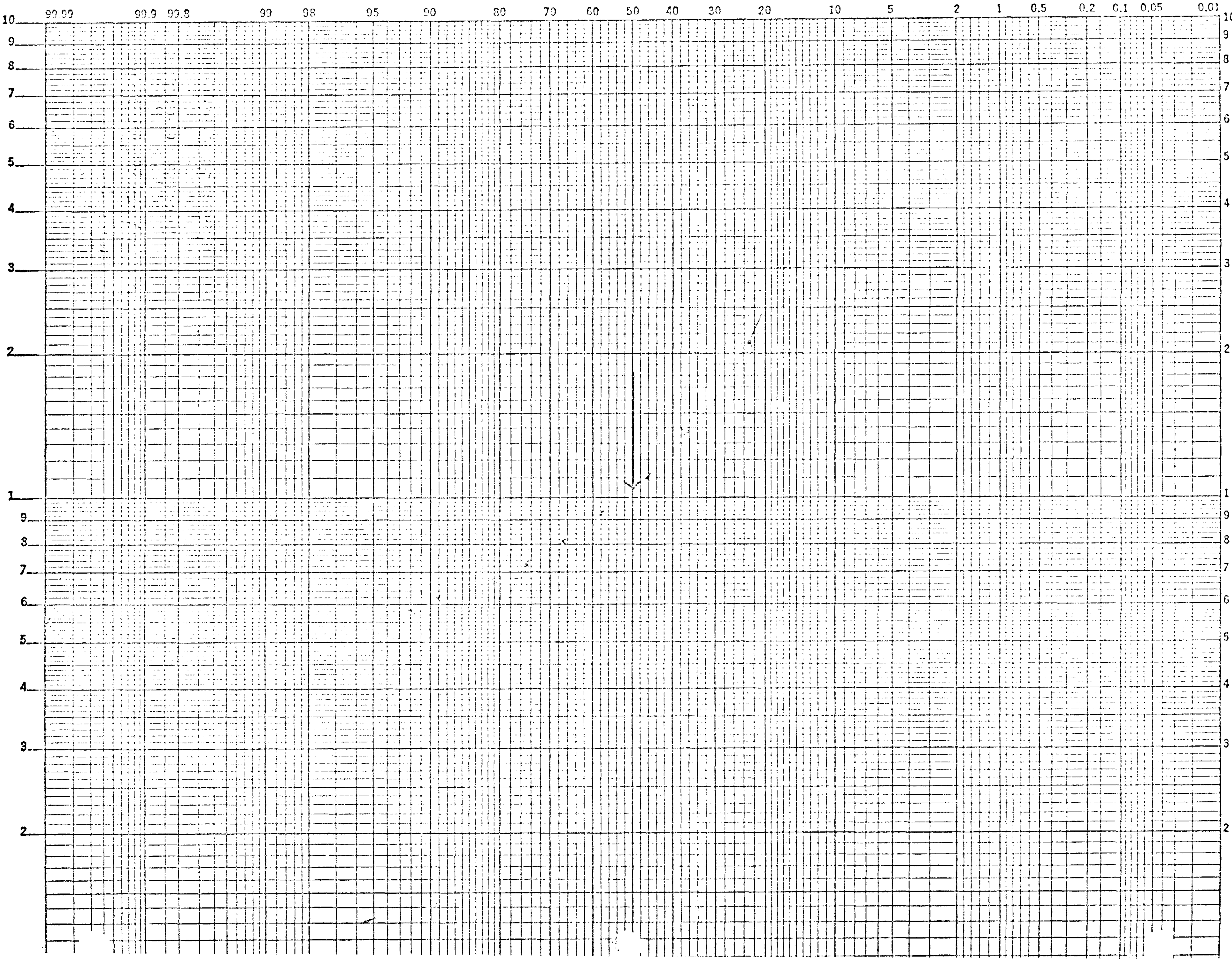
Table 2

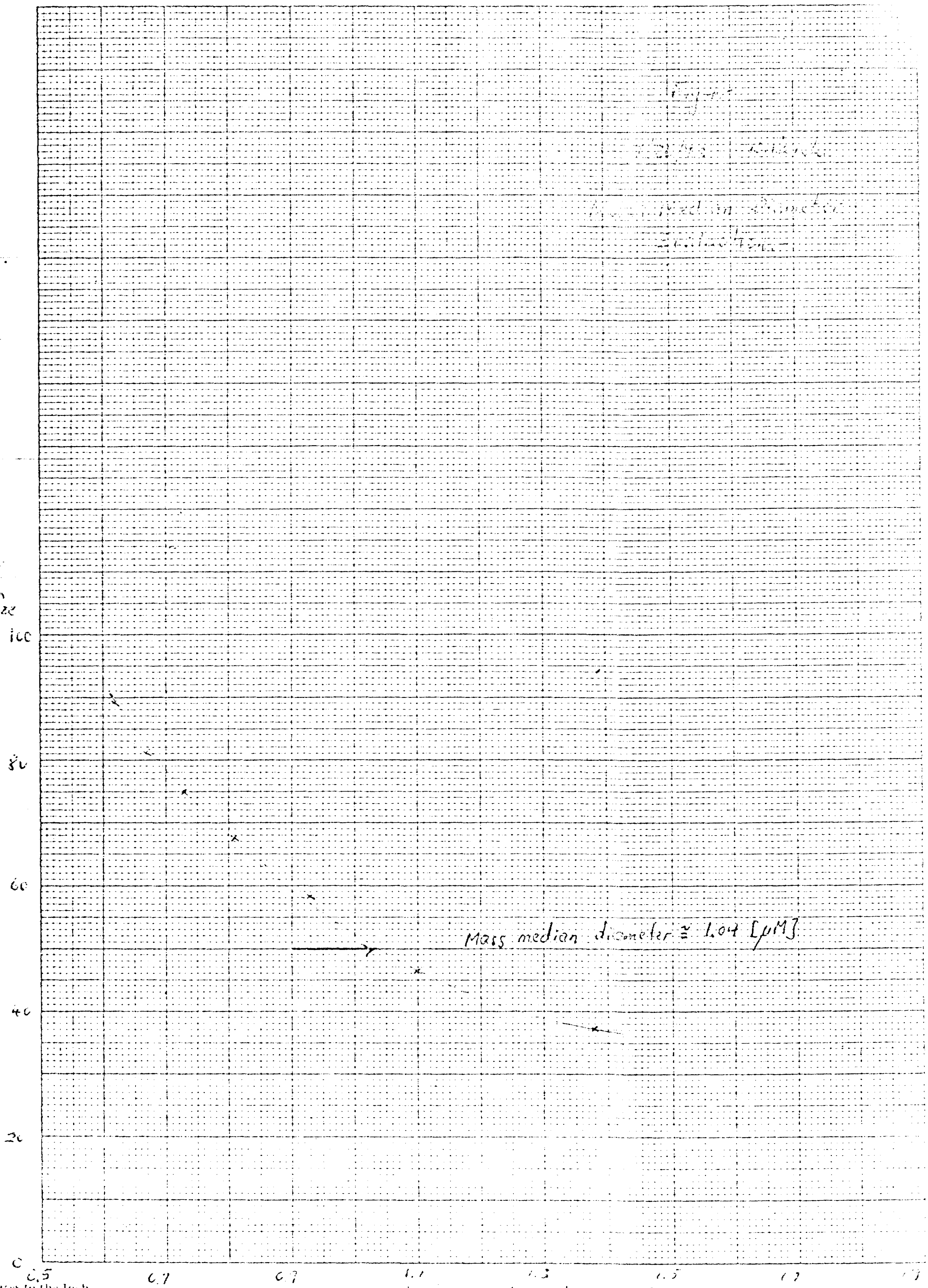
Particle Mass Distribution

Aerosol generation : Puritan
Centrifuge conditions: 10000 rpm, for 90 min

Sedimentation distance, [cm]	Fluorometer reading x30
0-0.4	5.5
0.5-0.8	11.0
0.9-1.2	2.0
1.3-1.6	5.0
1.7-2.0	3.0

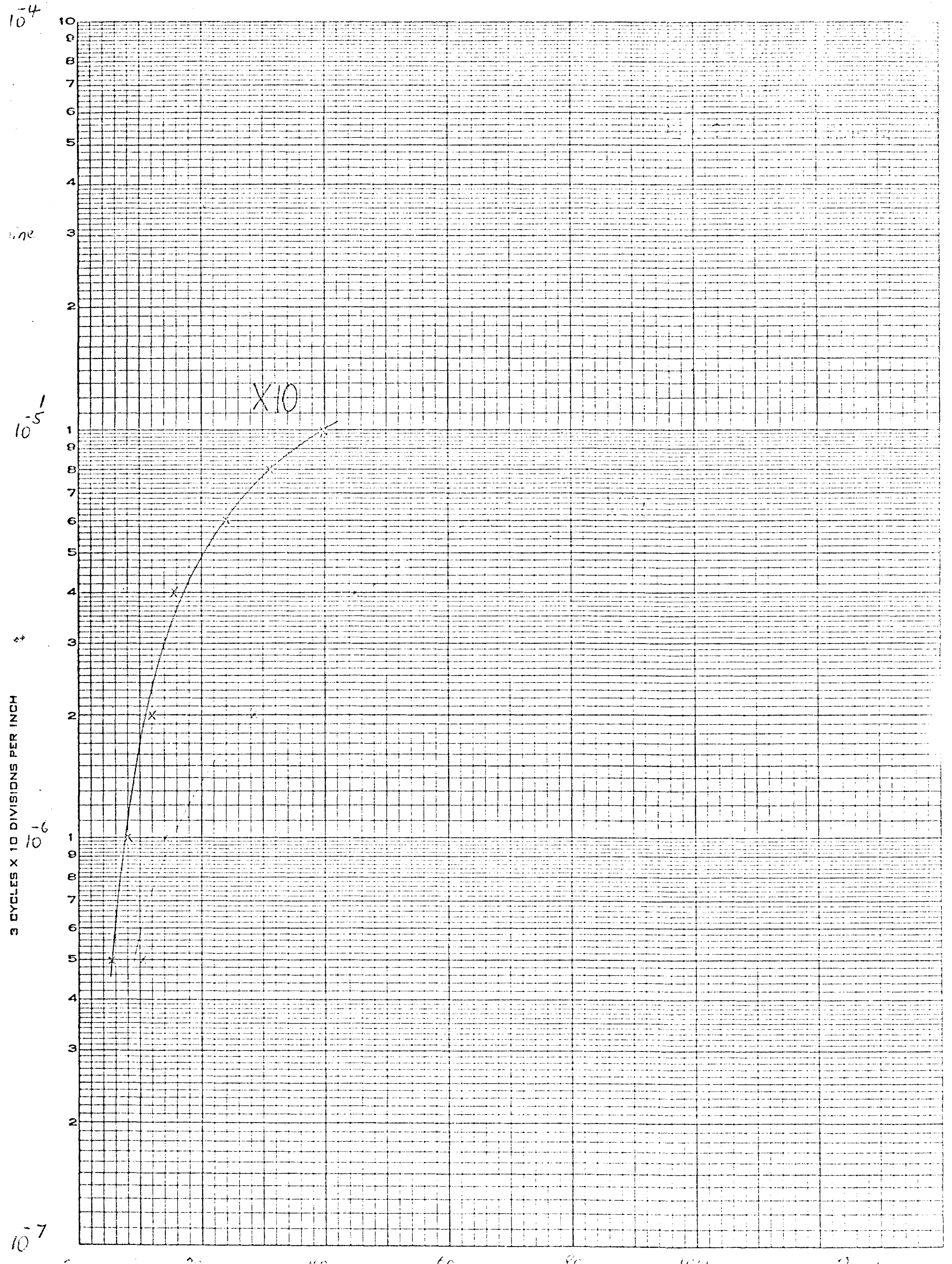
K+E PROBABILITY X 2 LOG CYCLES 46 8043 MADE IN U.S.A.
KEUFFEL & ESSER CO.



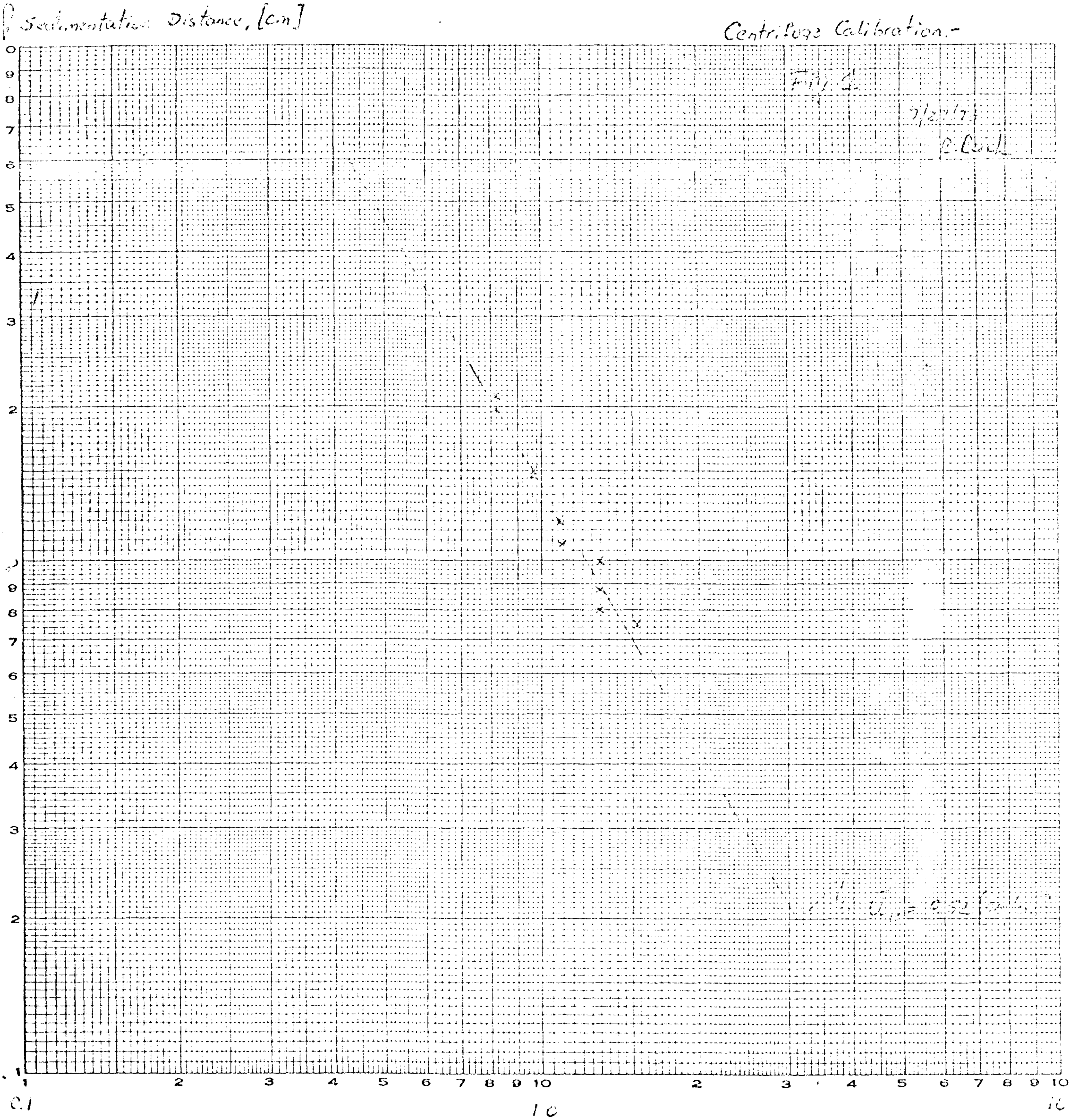


Squares to the Inch

Appendix


X10
3 CYCLES X 10 DIVISIONS PER INCH

Centrifuge Calibration.-



Aerodynamic Diameter [μM]

Bibliography.-

1.- Hochreiner, D. and Brown, P.M., Environ. Sci. Technol. 3, 830 (1969)

2.- Matteson, M.J., Boscoe, G.F. and Preining, O., Prepint School of Chemical Engineering, Georgia Tech, Atlanta(1972)

3.- Raabe, O.G., Aerosol Science 2, 289(1971)

4.- Matteson, M.J., and Stoeber, W., J. Colloid and Interface Science 23, 203 (1967)

5.- Matteson, M.J., Fox, J.J., and Preining, O., Nature Physical Science 238, 61 (1972).

A.) Calculations for Particle Analyzer.

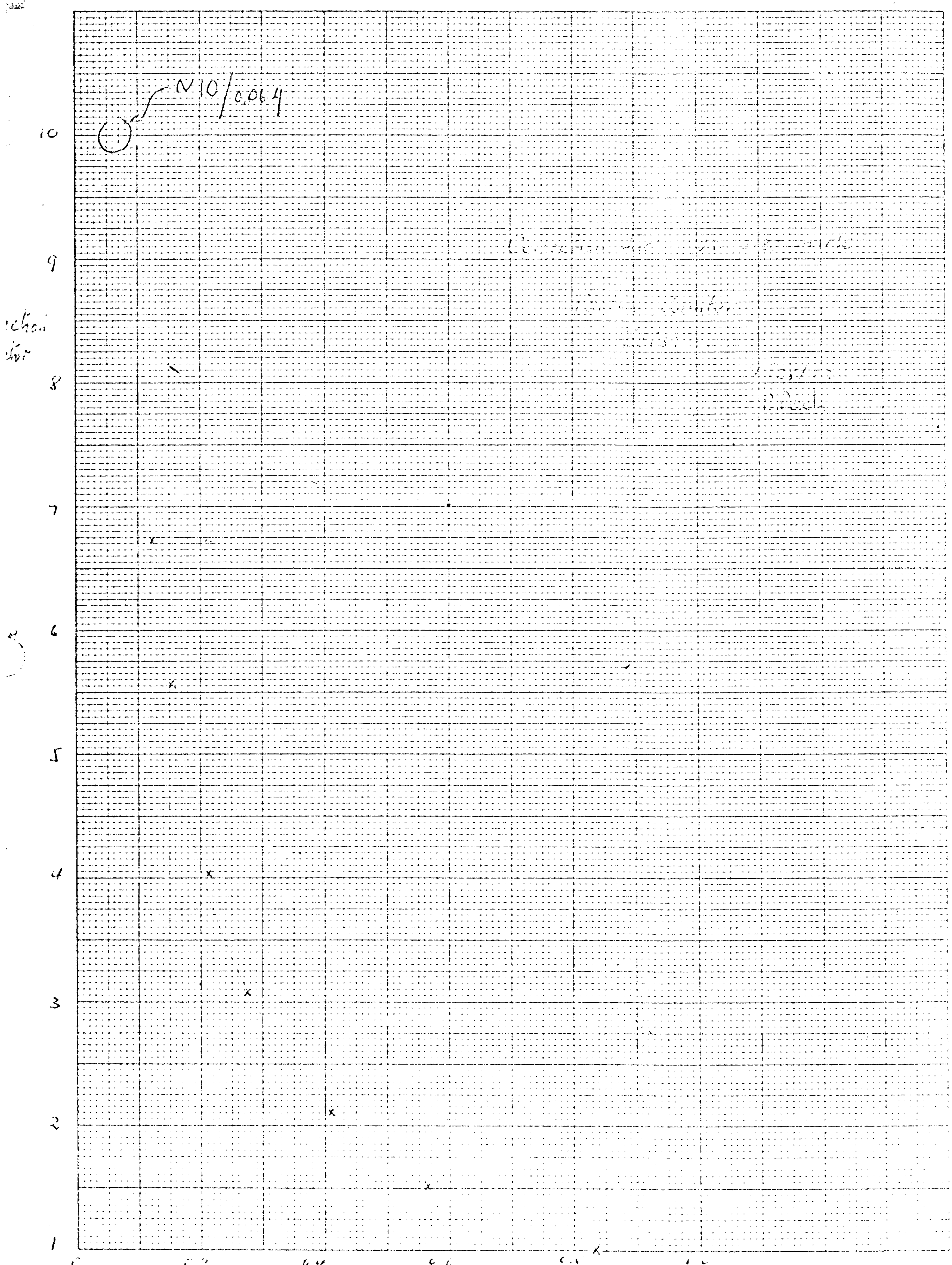
Operation: exponential increase of the measuring mark and standard range (1.2 ~ 27.7 mm)

I.) Nebulizer: De Vilbiss   Print No. D1-A

Amplification 4900 X

Counter No.	Interval Limit [microns]	Center X_i	Correction	Frequency	Corrected Frequency f_i
1	0.1222	0.1262	6.73	5	33.65
2	0.1303	0.1353	6.33	3	18.99
3	0.1393	0.1444	5.95	9	53.55
4	0.1484	0.1535	5.58	4	22.32
5	0.1585	0.1646	5.23	8	41.84
6	0.1696	0.1757	4.90	4	19.60
7	0.1808	0.1868	4.59	12	55.08
8	0.1929	0.200	4.30	10	43.0
9	0.206	0.2131	4.03	5	20.15
10	0.2202	0.2272	3.76	7	26.32
11	0.2353	0.2434	3.52	9	31.68
12	0.2505	0.2606	3.33	16	53.28
13	0.2676	0.2767	3.08	14	43.12
14	0.2858	0.2949	2.89	21	60.69
15	0.305	0.3151	2.72	9	24.48
16	0.3252	0.3353	2.53	9	22.77
17	0.3474	0.3595	2.39	15	35.85
18	0.3707	0.3838	2.23	11	24.53
19	0.3959			11	
					631.1

Counter No.	Limit	Center	Correction	Frequency	Corr. Frequency
19	0.3959			11	22.99
		0.409	2.09		
20	0.4222			5	9.8
		0.4363	1.96		
21	0.4505			10	18.3
		0.4666	1.83		
22	0.4818			11	18.81
		0.4979	1.71		
23	0.5141			14	22.68
		0.5313	1.62		
24	0.5484			4	6.04
		0.5666	1.51		
25	0.5858			14	19.88
		0.605	1.42		
26	0.6252			6	7.92
		0.6454	1.32		
27	0.6666			6	7.44
		0.6898	1.24		
28	0.7121			3	3.48
		0.7363	1.16		
29	0.7595			6	6.54
		0.7858	1.09		
30	0.8111			0	0
		0.8383	1.02		
31	0.8656			3	2.88
		0.8949	0.96		
32	0.9242			1	0.90
		0.9505	0.90		
33	0.9858			1	0.84
		1.0191	0.84		
34	1.0525			0	0
		1.0873	0.79		
35	1.1232			1	0.74
		1.1616	0.74		
36	1.1989			0	0
		1.2393	0.69		
37	1.2797			0	0
		1.3232	0.65		
38	1.3666			0	0
		1.4121	0.61		
39	1.4585			0	0
		1.507	0.57		
40	1.5565			0	0
		1.609	0.53		
41	1.6616			0	0
		1.7171	0.50		
42	1.7737			0	0
		1.8333	0.47		
43	1.8929			0	0
		1.9565	0.44		
44	2.0202				149.3
					631.1


N10/0.064
10
9
8
7
6
5
4
3
2
1

Counter No.	Limit	Center	Correction	Frequency	Corr. Freq.
44	2.0202			0	0
		2.0878	0.41		
45	2.1565			0	0
		2.2292	0.38		
46	2.302			0	0
		2.3787	0.36		
47	2.4565			0	0
		2.5393	0.34		
48	2.6222			0	0
		2.7101	0.32		

Particles smaller than 0.1222 μ : 755

Corrected frequency ≳ 755 × 7 > 5285

as correction factor is greater than 7.0

Counted particles < 15 %

if a size of 0.06 μ is assumed for this particles, a value for the correction factor can be extrapolated as about 10.

Corrected frequency ~ 7600

Counted particles ~ 8 %

I will make the analysis only for the counted particles.

Counter No.	Cumulative frequency	% cumulative frequency
1	34	4.34
2	53	6.76
3	107	13.65
4	129	16.45
5	171	21.81
6	191	24.36
7	246	31.38
8	289	36.86
9	309	39.41
10	335	42.73
11	367	46.81
12	420	53.57
13	463	59.06
14	524	66.84
15	549	70.03
16	572	72.96
17	608	77.55
18	633	80.74
19	656	83.67
20	666	84.95
21	684	87.25
22	703	89.67
23	726	92.60
24	732	93.37
25	752	95.92
26	760	96.94

Counter No.	Cumulative frequency	% cum fi
27	767	97.83
28	771	98.34
29	778	99.23
30	778	99.24
31	781	99.62
32	782	99.75
33	783	99.87
34	783	99.87
35	784	100.0

From the probability graph.

Geometric mean diameter $\cong$ 0.24 microns

Standard deviation $\cong \frac{D\,(84.13\%)}{0.24} = \frac{0.38}{0.24} = 1.58$

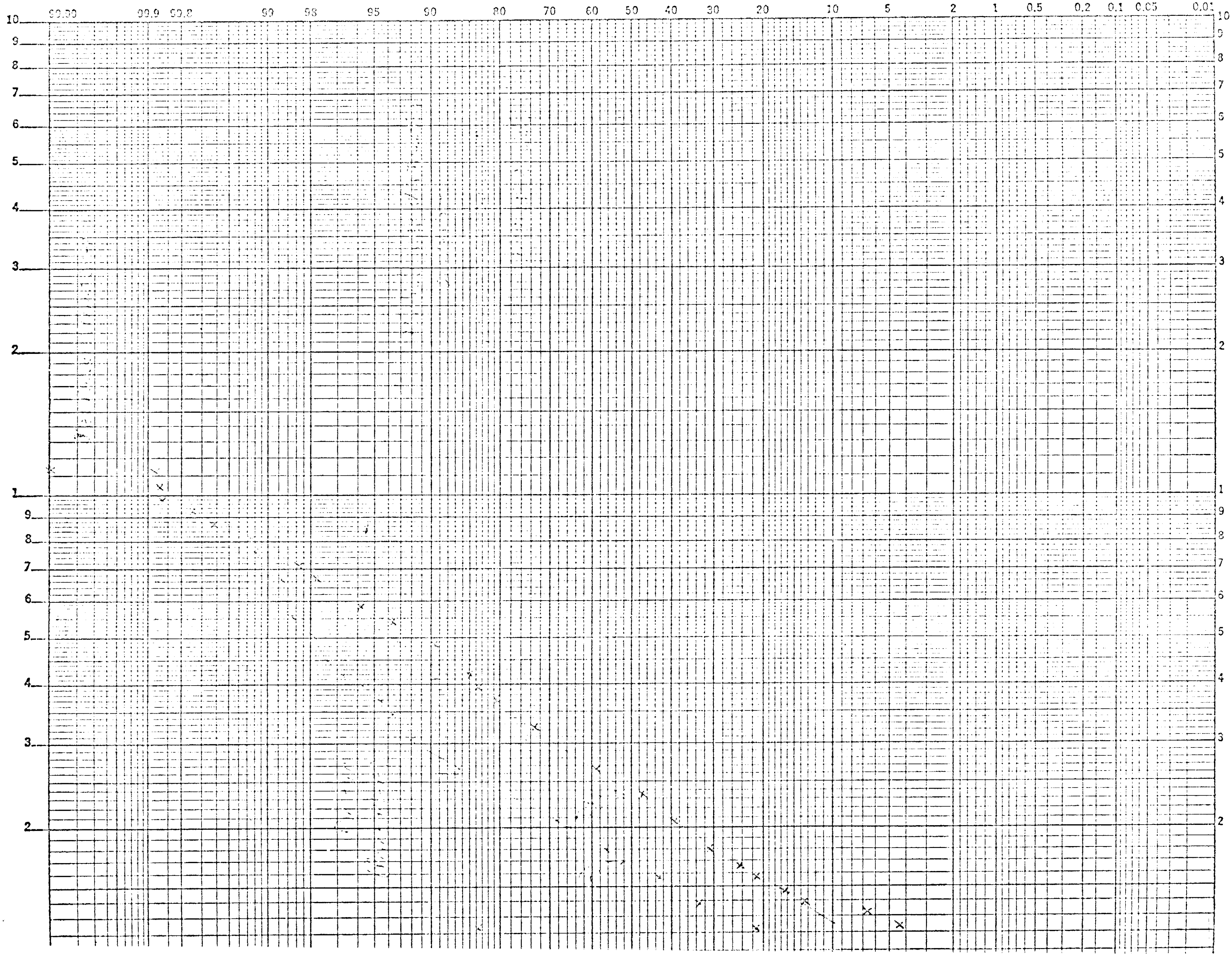
Mass median diameter $\cong$ 0.448 microns

from Hatch & Choate

$\ln D_m = \ln D_g + 3 \ln^2 \sigma_g$

K&E PROBABILITY X 2 LOG CYCLES 46 8043 MADE IN U.S.A.

KEUFFEL & ESSER CO.



II) Nebulizer . Puriton

9900 X   Print No. P1-A

Counter No.	Frequency fi	Corrected fi	Cumulative fi'	% fi'
1	28	188	188	21.68
2	9	57	245	28.25
3	8	48	293	33.79
4	3	17	310	35.75
5	12	63	373	43.02
6	12	59	432	49.82
7	13	60	492	56.74
8	12	52	544	62.74
9	14	56	600	69.20
10	14	53	653	75.31
11	11	39	692	79.81
12	13	43	735	84.77
13	5	15	750	86.50
14	11	32	782	90.19
15	6	16	798	92.04
16	3	8	806	92.96
17	2	5	811	93.54
18	4	9	820	94.57
19	5	11	831	95.84
20	4	8	839	96.77
21	2	4	843	97.23
22	0	0	843	97.23
		843		

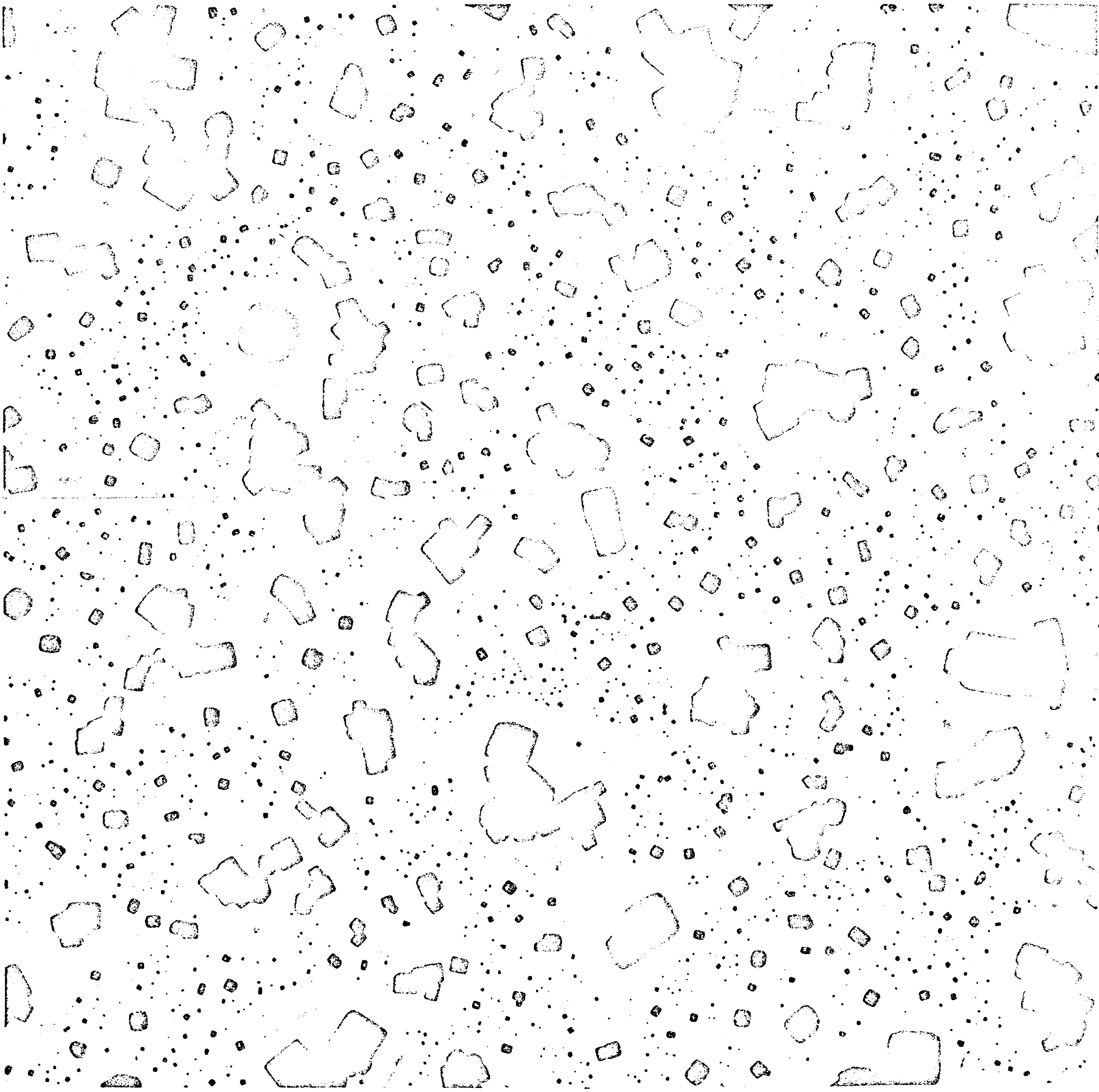
Counter	f_i	f_i	f_i'	$\% f_i'$
23	3	3	848	97.8
24	2	3	851	98.15
25	2	3	854	98.50
26	1	1	855	98.61
27	1	1	856	98.73
28	1	1	857	98.84
29	3	3	860	99.19
30	2	2	862	99.42
31	1	1	863	99.53
32	1	1	864	99.65
33	0	0	864	99.65
34	0	0	864	99.65
35	2	2	866	99.88
36	0	0	866	99.88
37	1	1	867	100.0
38	0	0		
39	0	↓		
40	0			
41	0			
42	0			
↓	↓			
48	0			

Particles smaller than 0.122 μm = 329
Corrected frequency ~ 3290
% particles counted ~ 26%

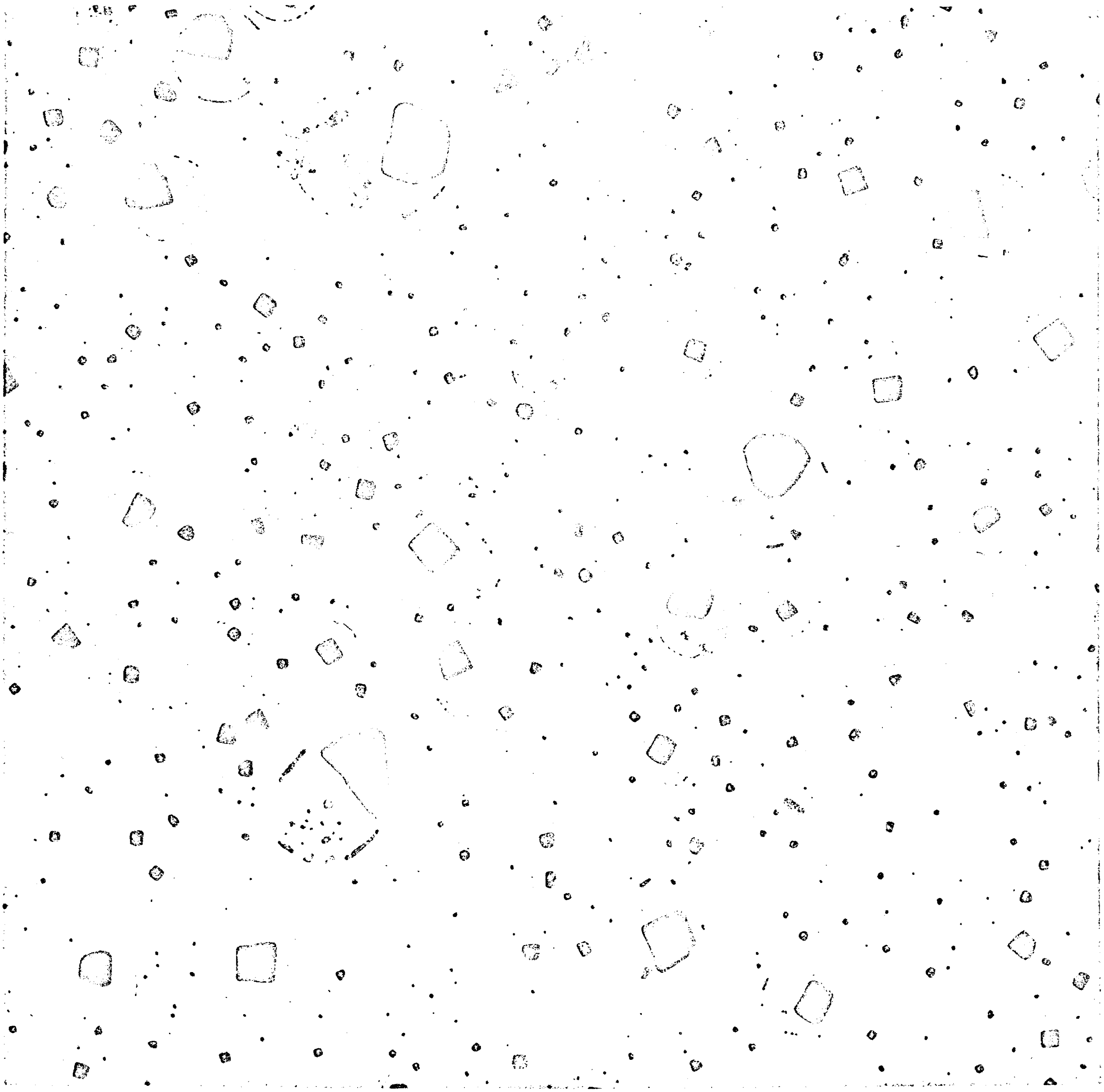
I will consider for the analysis only the counted particles

<u>Geometric mean diameter</u> : 0.17 [μm]
<u>Standard deviation</u> : $\frac{0.26}{0.17} = 1.53$

<u>Mass median diameter</u> : 0.291 [μm]



D1-A
9900X



P1-A
9900X

B) Calculations for the Royco particle analyzer:-

1) Conditions of operation:

sample air = 100 [cm^3/min]

nebulizer = De Vilbiss.

Size interval, [μ]	Frequency, f_i	Cumulative f_i'	% f_i'
8-16	6000	6000	13.19
4-8	22000	28000	61.54
2-4	11000	39000	85.71
1-2	4500	43500	95.60
0.5-1	2000	45500	100.0
	45500		

Geometric Mean Diameter ~ 5.3 [μ]

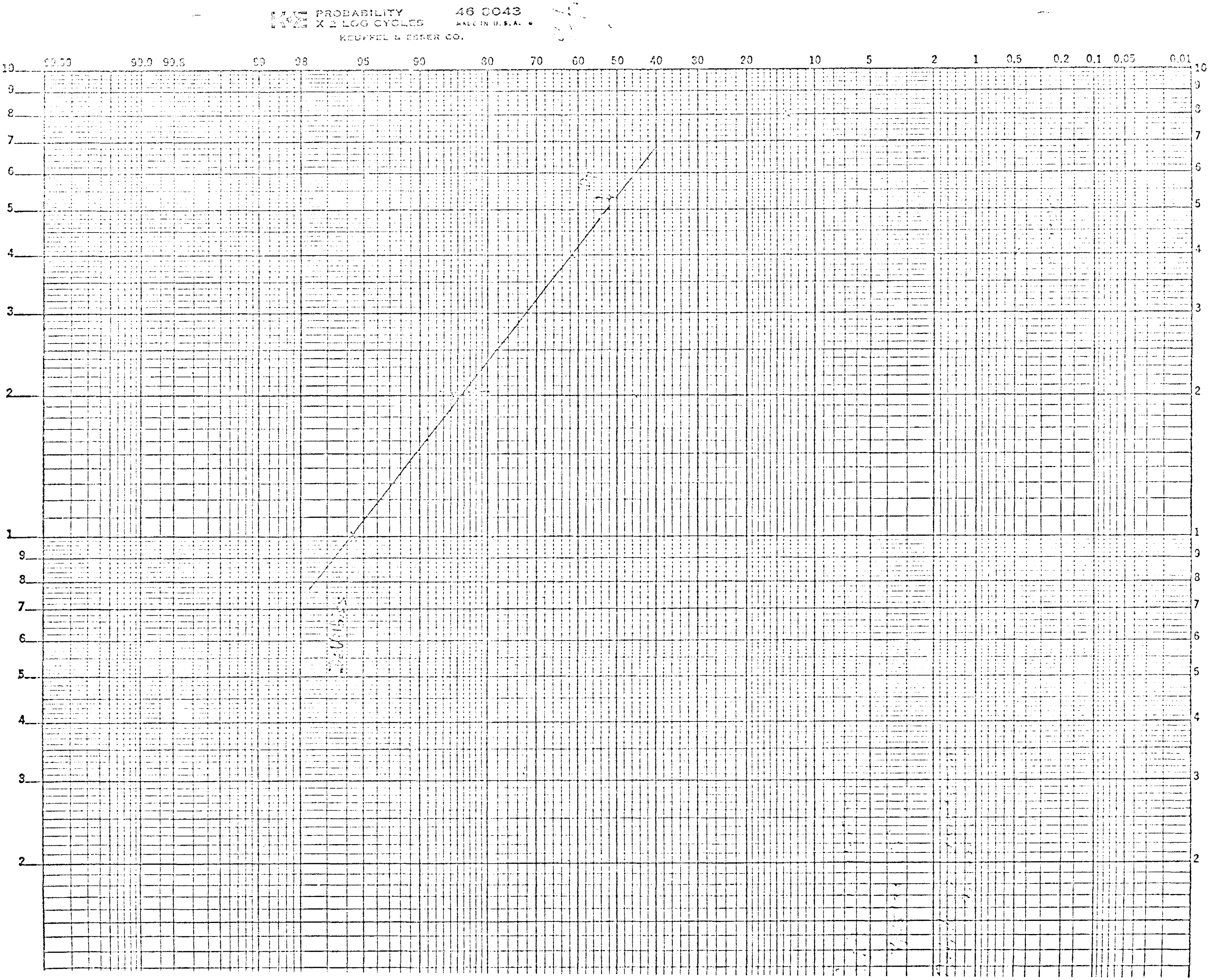
Standard Deviation ~ 2/5.3 = 0.38

Smallest particle counted = 0.5 μ

2) Sample air = 40 [cm^3/min]
nebulizer = puritan

Size interval [μ]	f_i	f_i'	%f_i'
8-16	0	0	0
4-8	300	300	0.48
2-4	28000	28300	45.42
1-2	21000	49300	79.13
0.5-1	13000	62300	100.0
	62300		

Too few points it is not possible to infer particle characteristics.-


K&E PROBABILITY X 2 LOG CYCLES
46 8043
MADE IN U.S.A.
KEUFFEL & ESSER CO.
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.1 0.05 0.01
10 9 8 7 6 5 4 3 2 1 9 8 7 6 5 4 3 2

Attachment V

Course Schedule for Masters Program

SURFACE SCIENCE AND TECHNOLOGY

Fall Quarter

1.	Course in Major Field	3-0-3
2.	Course in Major Field	3-0-3
3.	Course in Major Field	3-0-3
4.	Chemistry 6451 Electrochemistry	3-0-3

Winter Quarter

1.	Course in Major Field	3-0-3
2.	Course in Major Field	3-0-3
3.	Ch.E. 6613 Fine Particle Technology	3-0-3
4.	Met 6087 Heterogeneous Catalysis	3-0-3

Spring Quarter

1.	Course in Major Field	3-0-3
2.	Chem. 6451 Surface Equilibria	3-0-3
3.	Ch.E. 6610 Aerosol Technology	3-0-3
4.	Phys. 6235 Physics of Surfaces	3-6-5

Summer Quarter

1.	Chem., Ch.E., Physics 6753 Surface Science Laboratory	3-18-9
2.	Elective Course to be Approved by Program Director	3-0-3

Total Hours: 50

Hours in Major Field: At least 32

NSF FORM 98A

PLEASE READ INSTRUCTIONS ON REVERSE BEFORE COMPLETING

PART I—PROJECT IDENTIFICATION INFORMATION

1. Institution and Address	2. NSF Program	3. NSF Award Number
Georgia Institute of Technology Atlanta, GA 30332	Alternates in Higher Education	GZ-2896
	4. Award Period From 3/4/74 To 7/31/78	5. Cumulative Award Amount $75,000

6. Project Title

Surface Science and Technology

PART II—SUMMARY OF COMPLETED PROJECT *(FOR PUBLIC USE)*

The purpose of the grant was to develop a graduate level educational program in surface science and technology crossing several traditional disciplinary boundaries providing both course work and laboratory experience in surface chemistry, surface physics and surface technology. One objective of the grant was to develop graduate level courses and design a laboratory course containing modern surface science oriented experiments.

The program as developed provides an opportunity for first year graduate students in chemistry, physics or engineering to specialize in a currently important interdisciplinary area. The program permits students to complete all the requirements for a masters degree in their chosen field and take a thorough core of courses including a modern instrument-based graduate level laboratory course in surface science and technology.

The following graduate lecture courses were developed, approved and offered as a result of this grant:

- Ch.E. 6610 Aerosol Technology
- Ch.E. 6613 Fine Particle Technology
- Ch.E. 6787 Heterogeneous Catalysis
- Ch.E. 7750 Surface and Solution Properties of Polymers
- Chem. 6451 Surface Equilibria
- Chem. 6230 Electrochemistry of Surfaces
- Phys. 6239 Physics of Surfaces

In addition to the lecture courses, a graduate laboratory course was designed, approved and offered as Chem., Ch.E., Phys. 6753. These courses used facilities and instrumentation in several departments. Several of the experiments performed are:

1. Surface Area by Low Temperature Adsorption Measurements.
2. Pore Size Analysis by High Pressure Mercury Penetration.
3. Zeta Potential by Mass Transport Measurements.
4. Molecular Cross-Section by Film Balance Measurements.
5. Adsorption Thermodynamics from Gas-Solid Chromotography.
6. Surface Energies and Tensions from Contact Angle Measurements.
7. Surface Energy Anisotropy of Tungsten from Field-Ion Microscopy Studies.
8. Surface Studies of Copper Single Crystals Using the Back Reflection
9. Surface Analysis Using Auger, LEED, Electron Microprobe and Microscopy Technology
10. The Generation, Collection and Characterization of NaCl Aerosols.
11. The Kinetics of Electrode Reactions using DC Polarography.

PART III—TECHNICAL INFORMATION *(FOR PROGRAM MANAGEMENT USES)*

1. ITEM *(Check appropriate blocks)*	NONE	ATTACHED	PREVIOUSLY FURNISHED	TO BE FURNISHED SEPARATELY TO PROGRAM: Check (✓)	Approx. Date
a. Abstracts of Theses	✓				
b. Publication Citations	✓				
c. Data on Scientific Collaborators			✓		
d. Information on Inventions	✓				
e. Technical Description of Project and Results			✓		
f. Other *(specify)*					

2. Principal Investigator/Project Director Name *(Typed)* | 3. | 4. Date