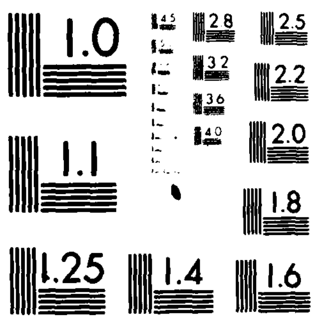
AD-A113 535 ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND ABERD--ETC F/G 20/6
EXTINCTION BY AEROSOL CLOUDS OF NONSPHERICAL PARTICLES AT ARBIT--ETC(U)
MAR 82 J F EMBURY
UNCLASSIFIED ARCSL-SP-81021 SBI-AD-E410 514 NL

1 OF 1

END
DATE
FILMED
5-82
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

CHEMICAL SYSTEMS LABORATORY SPECIAL PUBLICATION

ARCSL-SP-81021

EXTINCTION BY AEROSOL CLOUDS OF NONSPHERICAL PARTICLES AT ARBITRARY WAVELENGTHS

by

Janon F. Embury, Ph.D.

Research Division

March 1982

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
Chemical Systems Laboratory
Aberdeen Proving Ground, Maryland 21010

Disclaimer

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Disposition

Destroy this report when no longer needed. Do not return it to the originator.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ARCSL-SP-81021	2. GOVT ACCESSION NO. AD-A113 535	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EXTINCTION BY AEROSOL CLOUDS OF NONSPHERICAL PARTICLES AT ARBITRARY WAVELENGTHS		5. TYPE OF REPORT & PERIOD COVERED Special Publication January-June 1981
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Janon F. Embury, Ph.D.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Commander/Director, Chemical Systems Laboratory ATTN: DRDAR-CLB-PS Aberdeen Proving Ground, Maryland 21010		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1L162622A554-C
11. CONTROLLING OFFICE NAME AND ADDRESS Commander/Director, Chemical Systems Laboratory ATTN: DRDAR-CLJ-R Aberdeen Proving Ground, Maryland 21010		12. REPORT DATE March 1982
		13. NUMBER OF PAGES 14
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE NA

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aerosol cloud
Extinction spectra
Geometric optics limit
Rayleigh limit
Complex refractive index

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Extinction by a cloud consisting of many aerosol particles has been found to fall into two distinct wavelength regions which are adequately described by the geometric optics theory and the Rayleigh theory. Because the cloud consists of many different particles, the narrow extinction resonance structure of individual particles is lost, and extinction is governed by shape and size as predicted by geometric optics. At longer wavelengths, particles are in the Rayleigh region, and extinction for a large variety of particle shapes is predicted by the

(Continued on reverse side)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Contd)

Rayleigh ellipsoidal theory. The transition region lying between the applicability of these two simple theories occupies only about one wavelength decade.

PREFACE

The work described in this report was authorized under project 1L162622A554-C, Research in Aerosol/Obscuration Science. This work was started in January and completed in June 1981.

Reproduction of this document in whole or in part is prohibited except with permission of the Commander/Director, Chemical Systems Laboratory, ATTN: DRDAR-CLJ-R, Aberdeen Proving Ground, Maryland 21010. However, the Defense Technical Information Center and the National Technical Information Service are authorized to reproduce the document for United States Government purposes.

EXTINCTION BY AEROSOL CLOUDS OF NONSPHERICAL PARTICLES AT ARBITRARY WAVELENGTHS

1. INTRODUCTION

Most aerosol clouds consist of a polydispersion of particles. Distributions in size greatly simplify extinction spectra of clouds by averaging out the size-dependent extinction resonance peaks of individual particles. If the aerosol particles are not liquid, then they can be nonspherical and have a collection of orientations, surface irregularities, or a shape distribution, all of which serve to further average out narrow extinction resonance peaks. What remains of the extinction spectra may be treated by two limit theories; the geometric optics limit and the Rayleigh limit. In the geometric optics limit, extinction is governed by shape and size, independent of complex refractive index. In the Rayleigh limit extinction by an absorbing particle is governed by shape and complex refractive index, independent of size.

If the particles are convex, then the shape and size dependence in the geometric optics limit takes the form of a direct proportionality between extinction and surface area per unit volume. The Rayleigh ellipsoidal theory describes extinction by a wide variety of particle shapes represented by elliposoids. For example, high aspect ratio prolate spheroids, ellipsoids of revolution, can be used to represent fibers, and high aspect ratio oblate spheroids can be used to represent disks or flakes reasonably well.

2. DISCUSSION OF THEORY

The extinction coefficient, α, defines the beam transmittance, T, through a cloud as a function of its concentration, c, and pathlength l. A convenient set of consistent units puts the pathlength in meters, the concentration in grams per cubic meter, and the extinction coefficient in square meters per gram of material.

$$T = e^{-\alpha c l} \tag{1}$$

The extinction coefficient depends upon the geometric cross section, G, of a mass of material ρV, having extinction efficiency factor, Q. These must be averaged over particle size, w, and solid angle, Ω, to get an average extinction coefficient to represent the complete cloud.

$$\alpha = \left\langle \left\langle \frac{GQ}{\rho V} \right\rangle_\Omega \right\rangle_w \tag{2}$$

Assuming that the angular average of the product GQ is equal to the product of the averages and that the average efficiency factor is equal to two,

$$\alpha = 2 \left\langle \frac{\langle G \rangle_\Omega}{\rho V} \right\rangle_w \tag{3}$$

For convex particles it is well known that the geometric cross section averaged over all angles is equal to one-fourth the surface area, S.

$$\alpha = \frac{1}{2\rho} \left\langle \frac{S}{V} \right\rangle w \qquad (4)$$

Values of surface area per unit volume appear in table 1 for four typical shapes. These values for monodispersions appear in the first column, while the corresponding values for log normal polydispersions, having geometric standard deviations, σ, and number averaged dimensions subscripted n, appear in the second column. All dimensions are in microns when the density is in grams per cubic centimeter.

Table 1. Surface Area Per Unit Volume for Randomly Oriented Particles

Shape	Monodisperse	Polydisperse
	μ	μ
Sphere (r = radius)	$\frac{3}{r}$	$\frac{3}{r_n} e^{\frac{-5}{2} (\ln\sigma)^2}$
Cube (a = edge)	$\frac{6}{a}$	$\frac{6}{a_n} e^{\frac{-5}{2} (\ln\sigma)^2}$
Flake (t = thickness)	$\frac{2}{t}$	$\frac{2}{t_n} e^{\frac{-1}{2} (\ln\sigma)^2}$
Filament (r = radius)	$\frac{2}{r}$	$\frac{2}{r_n} e^{\frac{-3}{2} (\ln\sigma)^2}$

As these particles become smaller, they eventually become Rayleigh particles, the exact particle volume of transition depending upon shape and complex refractive index. Once this transition occurs, the extinction efficiency factor can no longer be considered as a constant equal to two, but instead becomes size dependent in such a way that it exactly cancels out the size dependence of the surface area per unit volume, resulting in a size-independent extinction coefficient so long as the particle is absorbing. Even if the particle's complex refractive index has a relatively small imaginary component, absorption will dominate over scatter at longer wavelengths because absorption efficiency factors have an explicit inverse wavelength dependence, while scatter eficiency factors have an explicit inverse fourth-power wavelength dependence. When the complex refractive index does not change rapidly with wavelength, the inverse wavelength dependence appears directly in the spectra for an absorbing particle, just as the inverse fourth-power wavelength dependence appears in the spectra for a dielectric particle. On the other hand, there will be peaks in the extinction spectra in wavelength regions of anomolous dispersion.

A theory treating nonspherical Rayleigh particles has been in existence since before the turn of the century and was developed by Rayleigh to predict the optical properties of small elliposoidal particles. Gans extended the theory to randomly oriented spheroids, elliposoids of revolution. The spheroid is a particularly valuable yet simple shape with the flexibility of predicting everything from rods, in the limit of high aspect ratio prolate spheroids, to discs, in the limit of high aspect ratio oblate spheroids. The extinction coefficient for an absorbing randomly oriented spheroid is

$$\alpha = \frac{8\pi^3}{3\lambda} \operatorname{Im} \left[\frac{1 - n^2}{4\pi + (n^2-1)P} + \frac{2\,(1 - n^2)}{4\pi + (n^2 - 1)\,(4\pi-P)/2}\right] \tag{5}$$

where P is the depolarization factor for the one unequal axis, n is the complex refractive index, and λ is the wavelength.

3. EXPERIMENTAL VERIFICATION

Aerosols are produced from powders by means of a nozzle which aspirates particles into a shear field produced by a sonic flow of air. This shear field has been sufficient to deagglomerate the particles without grinding individual particles against one another, as would occur in an air mill, to produce particles smaller than those originally manufactured. This stream of deagglomerated particles is injected into a 6-cubic-meter chamber, and the transmittance is measured using a Barnes Radiometer to continuously scan wavelengths throughout the mid infrared. In addition, the transmittance is measured at two laser lines, one in the visible and another in the near infrared. Filter samples of aerosol material are collected to determine mass concentrations and then, with the pathlength known, extinction coefficient spectra are calculated. This procedure has been used to produce the spectra in figures 1 and 2, where subsequent scans taken at 5-minute intervals lie at progressively higher extinction values. In figure 1 a graphite flake powder having a greater thickness than the graphite flake in figure 2 produced a flat spectra predicted for the averaged resonance region. The spectral scans in figure 1 made at later times represent progressively thinner flakes, as the thicker flakes fall out of the air first. In figure 2 the sequential scans are clumped together because the average flake thickness is smaller and should require more time to fall then those in figure 1. If the time required to fall is tripled, then the spectra in the second figure would be separated by only one-third the distance in the first figure, for example. This of course ignores the effect of initial delay due to falling through the vertical distance above the beam.

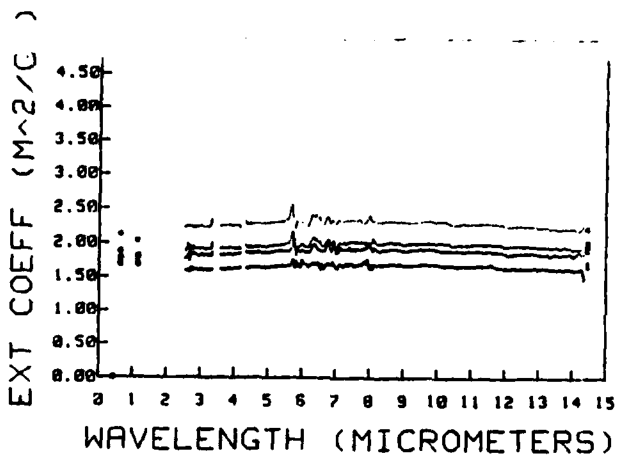


Figure 1. Dixon Graphite HPN-5

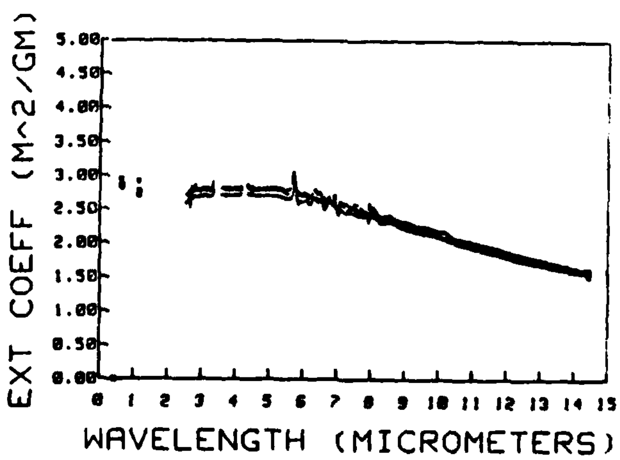


Figure 2. Asbury Graphite Micro #950

In figure 2, the transition between flat and Rayleigh inverse wavelength spectra occurs at wavelengths around 5 microns. This occurs in figure 2, but not in figure 1, for two reasons. First, the flake particles in figure 2 are nearly half the thickness of those in figure 1. Second, the major flake dimensions in figure 2 are only about a tenth those in figure 1, so that the transition at a fixed thickness would occur at shorter wavelengths due to the smaller aspect ratio.

4. CONCLUSION

Extinction spectra for a collection of particles in a cloud have been demonstrated to be either flat, in the case of larger particles, or to have structure superimposed onto an inverse wavelength dependence, in the case of smaller particles. Flat spectra occur as a result of the superposition of numerous, individual particle-resonant structure spectra where the particles have a variety of sizes and orientations, both of which influence the wavelength position of resonant peaks. Smaller particle spectra is structured where refractive index changes take place rapidly with wavelength. An underlying inverse wavelength dependence appears in small, absorbing particle spectra because the extinction efficiency factor has such explicit dependence. The transition wavelengths lying between the short wavelength, flat and longer wavelength, Rayleigh-structured spectral regions are determined by particle size and shape, which move the plateau up and down, as well as by the refractive index and aspect ratio, which move the Rayleigh spectra up and down. Analytic expressions were given for a variety of shapes, both monodisperse and polydisperse, outside the Rayleigh region. An analytic expression was also given for the spheroid in the Rayleigh region.

DISTRIBUTION LIST 5

Names	Copies
CHEMICAL SYSTEMS LABORATORY	
ATTN: DRDAR-CLB-C	1
ATTN: DRDAR-CLB-P	1
ATTN: DRDAR-CLB-PA	1
ATTN: DRDAR-CLB-R	1
ATTN: DRDAR-CLB-T	1
ATTN: DRDAR-CLB-TE	1
ATTN: DRDAR-CLC	1
ATTN: DRDAR-CLF	1
ATTN: DRDAR-CLJ-R	2
ATTN: DRDAR-CLJ-L	3
ATTN: DRDAR-CLJ-M	1
ATTN: DRDAR-CLJ-P	1
ATTN: DRDAR-CLT-E	1
ATTN: DRDAR-CLN	1
ATTN: DRDAR-CLN-D	1
ATTN: DRDAR-CLN-S	3
ATTN: DRDAR-CLN-ST	2
ATTN: DRDAR-CLR-I	1
ATTN: DRDAR-CLW-C	1
ATTN: DRDAR-CLW-P	1
ATTN: DRDAR-CLY-A	1
ATTN: DRDAR-CLY-R	6
COPIES FOR AUTHOR(S):	
Research Division	1
RECORD SET: ATTN: DRDAR-CLB-A	1
DEPARTMENT OF DEFENSE	
Defense Technical Information Center ATTN: DTIC-DDA-2 Cameron Station, Building 5 Alexandria, VA 22314	2
Director Defense Intelligence Agency ATTN: DB-4G1 Washington, DC 20301	1
Special Agent in Charge ARO, 902d Military Intelligence GP ATTN: IAGPA-A-AN Aberdeen Proving Ground, MD 21005	1

Names	Copies
Commander SED, HQ, INSCOM ATTN: IRFM-SED (Mr. Joubert) Fort Meade, MD 20755	1
DEPARTMENT OF THE ARMY	
HQDA (DAMO-NCC) WASH DC 20310	1
Deputy Chief of Staff for Research, Development & Acquisition	
ATTN: DAMA-CSS-C	1
ATTN: DAMA-ARZ-D Washington, DC 20310	1
US Army Research and Standardization Group (Europe) ATTN: DRXSN-E-SC Box 65, FPO New York 09510	1
HQDA (DAMI-FIT) WASH, DC 20310	1
Commander DARCOM, STITEUR ATTN: DRXST-STI Box 48, APO New York 09710	1
Commander US Army Science & Technology Center-Far East Office ATTN: MAJ Borges APO San Francisco 96328	1
Commander 2d Infantry Division ATTN: EAIDCOM APO San Francisco 96224	1
Commander 5th Infantry Division (Mech) ATTN: Division Chemical Officer Fort Polk, LA 71459	1

Commander
US Army Nuclear & Chemical Agency
ATTN: MONA-WE (LTC Pelletier) 1
7500 Backlick Rd, Bldg 2073
Springfield, VA 22150

Army Research Office
ATTN: DRXRO-CB 1
ATTN: DRXRO-MA 1
P.O. Box 12211
Research Triangle Park, NC 27709

OFFICE OF THE SURGEON GENERAL

Commander
US Army Medical Bioengineering Research
and Development Laboratory
ATTN: SGRD-UBD-AL 1
Fort Detrick, Bldg 568
Frederick, MD 21701

Headquarters
US Army Medical Research and
Development Command
ATTN: SGRD-PL 1
Fort Detrick, MD 21701

Commander
USA Medical Research Institute of
Chemical Defense
ATTN: SGRD-UV-L 1
Aberdeen Proving Ground, MD 21010

US ARMY HEALTH SERVICE COMMAND

Superintendent
Academy of Health Sciences
US Army
ATTN: HSA-CDH 1
ATTN: HSA-IPM 1
Fort Sam Houston, TX 78234

US ARMY MATERIEL DEVELOPMENT AND
READINESS COMMAND

Commander
US Army Materiel Development and
Readiness Command
ATTN: DRCLDC 1
ATTN: DRCSF-P 1
5001 Eisenhower Ave
Alexandria, VA 22333

Project Manager Smoke/Obscurants
ATTN: DRCPM-SMK 3
Aberdeen Proving Ground, MD 21005

Commander
US Army Foreign Science & Technology Center
ATTN: DRXST-MT3 1
220 Seventh St., NE
Charlottesville, VA 22901

Director
US Army Materiel Systems Analysis Activity
ATTN: DRXSY-FJ (SAWG) 1
ATTN: DRXSY-MP 1
ATTN: DRXSY-CA (Mr. Metz) 2
Aberdeen Proving Ground, MD 21005

Commander
US Army Missile Command
Redstone Scientific Information Center
ATTN: DRSMI-ROC (B. Fowler) 1
ATTN: DRSMI-RPR (Documents) 1
Redstone Arsenal, AL 35809

Director
DARCOM Field Safety Activity
ATTN: DRXOS-C 1
Charlestown, IN 47111

Commander
US Army Natick Research and
Development Command
ATTN: DRDNA-VR 1
ATTN: DRDNA-VT 1
Natick, MA 01760

US ARMY ARMAMENT RESEARCH AND
DEVELOPMENT COMMAND

Commander
US Army Armament Research and
Development Command
ATTN: DRDAR-LCA-L 1
ATTN: DRDAR-LCE 1
ATTN: DRDAR-LCE-C 1
ATTN: DRDAR-LCU 1
ATTN: DRDAR-LCU-CE 1
ATTN: DRDAR-PMA (G.R. Sacco) 1
ATTN: DRDAR-SCA-W 1
ATTN: DRDAR-TSS 5
ATTN: DRCPM-CAWS-AM 1
ATTN: DRCPM-CAWS-SI 1
Dover, NJ 07801

Commander
USA ARRADCOM
ATTN: DRDAR-QAC-D 5
Aberdeem Proving G'ound, MD 21010

Director
Ballistic Research Laboratory
ARRADCOM
ATTN: DRDAR-TSB-S 1
Aberdeen Proving Ground, MD 21005

US ARMY ARMAMENT MATERIEL READINESS COMMAND

Commander
US Army Armament Materiel Readiness Command
ATTN: DRSAR-ASN 1
ATTN: DRSAR-PDM 1
ATTN: DRSAR-SF 1
Rock Island, IL 61299

Commander
US Army Dugway Proving Ground
ATTN: Technical Library Docu Sect 1
Dugway, UT 84022

US ARMY TRAINING & DOCTRINE COMMAND

Commandant
US Army Infantry School
ATTN: NBC Division 1
Fort Benning, GA 31905

Commandant
USAMP&CS/TC&FM
ATTN: ATZN-CM-CDM 1
Fort McClellan, AL 36205

Commander
US Army Infantry Center
ATTN: ATSH-CD-MS-C 1
Fort Benning, GA 31905

Commander
US Army Infantry Center
Directorate of Plans & Training
ATTN: ATZB-DPT-PO-NBC 1
Fort Benning, GA 31905

Commander
USA Training and Doctrine Command
ATTN: ATCD-Z 1
Fort Monroe, VA 23651

Commander
USA Combined Arms Center and Fort Leavenworth
ATTN: ATZL-CA-COG 1
ATTN: ATZL-CAM-IM 1
Fort Leavenworth, KS 66027

Commander
US Army TRADOC System Analysis Activity
ATTN: ATAA-SL 1
White Sands Missile Range, NM 88002

Commander/Director
Atmospheric Sciences Laboratory
ATTN: DELAS-EO (Dr. Niles) 5
ATTN: DELAS-EO-MO 1
White Sands Missile Range, NM 88002

US ARMY TEST & EVALUATION COMMAND

Commander
US Army Test & Evaluation Command
ATTN: DRSTE-CM-F 1
ATTN: DRSTE-CT-T 1
Aberdeen Proving Ground, MD 21005

DEPARTMENT OF THE NAVY

Commander
Naval Air System Command
AIR-310C (H. Rosenwasser) 1
Washington, DC 20361

Commander
Naval Explosive Ordnance Disposal Facility
ATTN: Army Chemical Officer (Code AC-3) 1
Indian Head, MD 20640

Commander
Naval Weapons Center
ATTN: Technical Library (Code 343) 1
China Lake, CA 93555

Commanding Officer
Naval Weapons Support Center
ATTN: Code 5042 (Dr. B.E. Douda) 1
Crane, IN 47522

US MARINE CORPS

Director, Development Center
Marine Corps Development and
Education Command
ATTN: Fire Power Division
Quantico, VA 22134 — 1

DEPARTMENT OF THE AIR FORCE

HQ Foreign Technology Division (AFSC)
ATTN: TQTR
Wright-Patterson AFB, OH 45433 — 1

HQ AFLC/LOWMM
Wright-Patterson AFB, OH 45433 — 1

OUTSIDE AGENCIES

Battelle, Columbus Laboratories
ATTN: TACTEC
505 King Avenue
Columbus, OH 43201 — 1

Toxicology Information Center, WG 1008
National Research Council
2101 Constitution Ave., NW
Washington, DC 20418 — 1

ADDITIONAL ADDRESSEE

Commander
US Army Environmental Hygiene Agency
ATTN: Librarian, Bldg 2100
Aberdeen Proving Ground, MD 21010 — 1

Stimson Library (Documents)
Academy of Health Sciences
Bldg. 2840
Fort Sam Houston, TX 78234 — 1

DATE
FILMED

5-8