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ELECTRO-OPTICAL TRANSMISSION AND LIQUID WATER CONTENT OF FOGS AND CLOUDS

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Relatively good agreement (generally within 20%) was found between two direct filtration methods, one of which employed a top loading balance. The use of a reference impaction assembly is imperative when making absolute measurements of liquid water content. The experimental assembly designed to measure simultaneously extinction coefficient and liquid water content has been completed and used. Simultaneous measurements of extinction coefficient, wavelength, and liquid water content have been successfully made, and do not closely match theoretical predictions. A new device for measuring the homgeneity of clouds/..

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) inside a cloud chamber has been developed.

ELECTRO-OPTICAL TRANSMISSION AND LIQUID WATER CONTENT OF FOGS AND CLOUDS

Absolute methods for the measurement of liquid water content of laboratory and of natural cloud were described in the 9th Interim Report. Relatively good agreement (generally within 20%) was found between two direct filtration methods, one of which employed a top loading balance. It was pointed out that the use of a reference impaction assembly was imperative when making absolute measurements of liquid water content.

This report gives an account of work on three main fronts:

(a) Simultaneous measurements of extinction coefficient at CO_2 laser wavelengths and liquid water content for laboratory generated cloud.

(b) A new technique employed to determine to what extent a cloud is homogeneous along its transmission path.

(c) The investigation of relationships between extinction and backscatter of electromagnetic radiation particularly at CO_2 laser wavelengths.

Progress on the above areas is now reported:

(a) The experimental assembly designed to measure simultaneously extinction coefficient and liquid water content has been successfully set up and employed. Details of the apparatus and ancillary equipment have been described in previous interim reports. Both broad cloud droplet size distribution using "cool-mist" vapourizers and narrow droplet size distributions using a De Vilbiss model 65 ultrasonic nebulizer were used in a 1 m^3 laboratory chamber.

Simultaneous measurements of extinction coefficient σ_e, m^{-1} at CO_2 laser wavelengths λ = 10.591 micrometres and liquid water content W, g m^{-3} using direct filtration methods are shown in Figure 1. The error bars of the liquid water content parameter indicates the spread in liquid water using the separate filtration methods as described in the 9th Interim Report[1]. Isolated points without error bars in the figure indicate measurements with the vertical tube filtration method only.

The measured points reveal the ratio σ_e/W being less than the predicted value of 147, shown by the solid line in Figure 1, where the predicted ratio is given by

$$\sigma_e/W = 3\pi C/2\rho\lambda \qquad (1)$$

as shown by Chýlek[2]. The density of water is given by ρ and the coefficient c is equal to the slope of a straight line approximating the efficiency factor for extinction Q_{ext} by

$$Q_{ext}\ (x_1\lambda) = C(\lambda)x \qquad (2)$$

The size parameter x is defined by the ratio of the particle circumference to the wavelength. The conditions under which approximation (2) are valid have been discussed elsewhere [2,3].

The largest deviations from prediction occur for the broader size distributions as produced by the cool mist vaporizers. It is clear [2,3] that σ_e/W will be overpredicted with increase in droplet size. Accordingly modifications have been made to the droplet generators to reduce the larger drop population by impaction baffle techniques. Measurements of σ_e/W using a narrower size distribution range will be reported on in the next report. Efforts will also be made to carry out measurements at relatively low values of cloud water content.

(b) A homogeneous path is usually assumed when the extinction coefficient σ_e is derived from the Beers-Lambert law of

$$I/I_o = \exp\ (-\sigma_e L) \qquad (3)$$

where I_o is the incident radiation intensity and I is the intensity after traversal of path length L through a (cloud) medium. Departures from cloud homogeneity will overestimate the inferred extinction coefficient.

A useful technique for determining the extent of cloud homogeneity has been devised in this laboratory. The apparatus essentially consists of a radiation detector which is mounted inside the cloud housing, with the detector being translated through the cloud on a threaded rod assembly. A He-Ne laser is directed onto the detector which is a UDT FIL-100V silicon photodiode operating in the photovoltaic mode. The detector mounting is driven by a motor control module (whilst the scanning rate of the detector is set by a controlled oscillator frequency, with 5 V amplitude). The direction of rotation of the threaded rod can be reversed by switching a 100 μF capacitor between the motor inputs. The motor and control electronics are fan cooled. Scanning rates of between 30 seconds and 3 minutes are readily achieved whilst mechanical gears are needed to extend this range. A narrow jet of cloud free air is continuously directed across the face of the detector during a scan in order to prevent cloud deposition on the detector itself.

A non-cloud scan ensured a uniform response of the detector along the transmission path. With the cloud droplet generators assymetrically positioned in the cloud housing, Fig. 2 shows the degree of inhomogeneity in the cloud over a transmitted path of 0.7 m in terms of optical depth, $\ell n\ (I/I_0)$ plotted against path distance. A good representation of cloud homogeneity along the transmission path is shown in Fig. 3 for the cloud generators positioned in their normal symmetrical positioning in the laboratory chamber, where a 45 degree slope entails 100 per cent homogeneity. Most cloud scans with this technique have yielded results similar to those in Fig.3 indicating a high degree of homogeneity of cloud in the chamber. This is an important finding for our particular cloud chamber in that it obviates the need for several liquid water measurement devices to be placed along the transmission path. It also implies that in general extinction measurements in the chamber do not require correction for inhomogeneity along the transmission path. It should be remarked that checks for inhomogeneity are particularly desirable in chambers of large dimension.

(c) Relationships between electro-optical transmission and backscatter of water clouds at CO_2 laser wavelengths.

Although CO_2 laser technology, which incorporates CO_2 lidar work, is now developing rapidly, efforts to extract attenuation from a CO_2 lidar return have to date been largely statistical in nature. A knowledge of the relationship between backscatter and attenuation would allow the determination of attenuation and backscatter from the return signal of a lidar system using the analytical inversion solution of Klett [4]. However, very little work has been done to date on relating backscatter to extinction at CO_2 laser wavelengths. Some of the principal recommendations which resulted from the workshop on global large aerosols, compiled by Freeman F. Hall, Jr.,[5] Chief of the Doppler Lidar program at NOAA, included the necessity of CO_2 backscatter and extinction measurements - both requiring experimental and theoretical work.

Technical Objectives

(i) It is proposed to carry out simultaneous measurements of extinction and backscatter for a variety of cloud size distributions under controlled laboratory conditions at CO_2 laser wavelengths.

(ii) Analysis of possible relationships between extinction and backscatter which incorporates size distribution dependencies will also be made.

The normalized backscatter cross-section (efficiency factor) Q_{BKS} (m_1 x) for water is plotted in Fig. 4 as a function of size parameter x using an updated Mie-Lorenz scattering computer code using Wiscombe's [6] algorithm, details of which are described more fully in the 2nd Annual Progress Report [7]. It is seen that the normalized backscatter cross-section oscillates about a constant value for $x > 6$ (radius $r > 10$ μm at $\lambda = 10.591$ μm). In view of the fact that calculations show that the extinction cross-section is constant for increasing x for $x > 8$ at $\lambda = 10.591$ μm, we can predict that extinction/backscatter will be largely independent of x also for $x > 6$-8.

Calculations indeed show that the extinction to backscatter ratio σ_e/σ_b at $\lambda = 10.591$ μm (P20 CO_2 laser wavelength line) oscillates about a constant value for water droplet radius > 8.5 μm as shown in Fig.5. We predict that broad cloud drop size distributions will give rise to relatively constant values of extinction to backscatter ratios at CO_2 laser wavelengths.

An experimental arrangement is currently being set up to make simultaneous measurements of backscatter coefficient and extinction coefficient at CO_2 laser wavelengths over a relatively wide range of cloud droplet size. A liquid nitrogen cooled cadmium mercury telluride (CMT) detector will be used to measure the backscatter signal. A black body source with one inch diameter cavity with temperature controller, (Electro Optical Industries Inc. Model WS 153) has recently been purchased in order to calib ate the CMT detector. This will be achieved through the use of a lock-in amplifier (EG & G Brookdeal 9501) in conjunction with a EG & G Brookdeal 9479 light chopper. The remaining experimental techniques employed will be broadly similar to that used at wavelength $\lambda = 0.6328\ \mu m$ in this laboratory and described in some detail elsewhere [8,9]. Results of backscatter/extinction measurements in laboratory cloud in the 10 micrometre wavelength range will be described fully in the next report.

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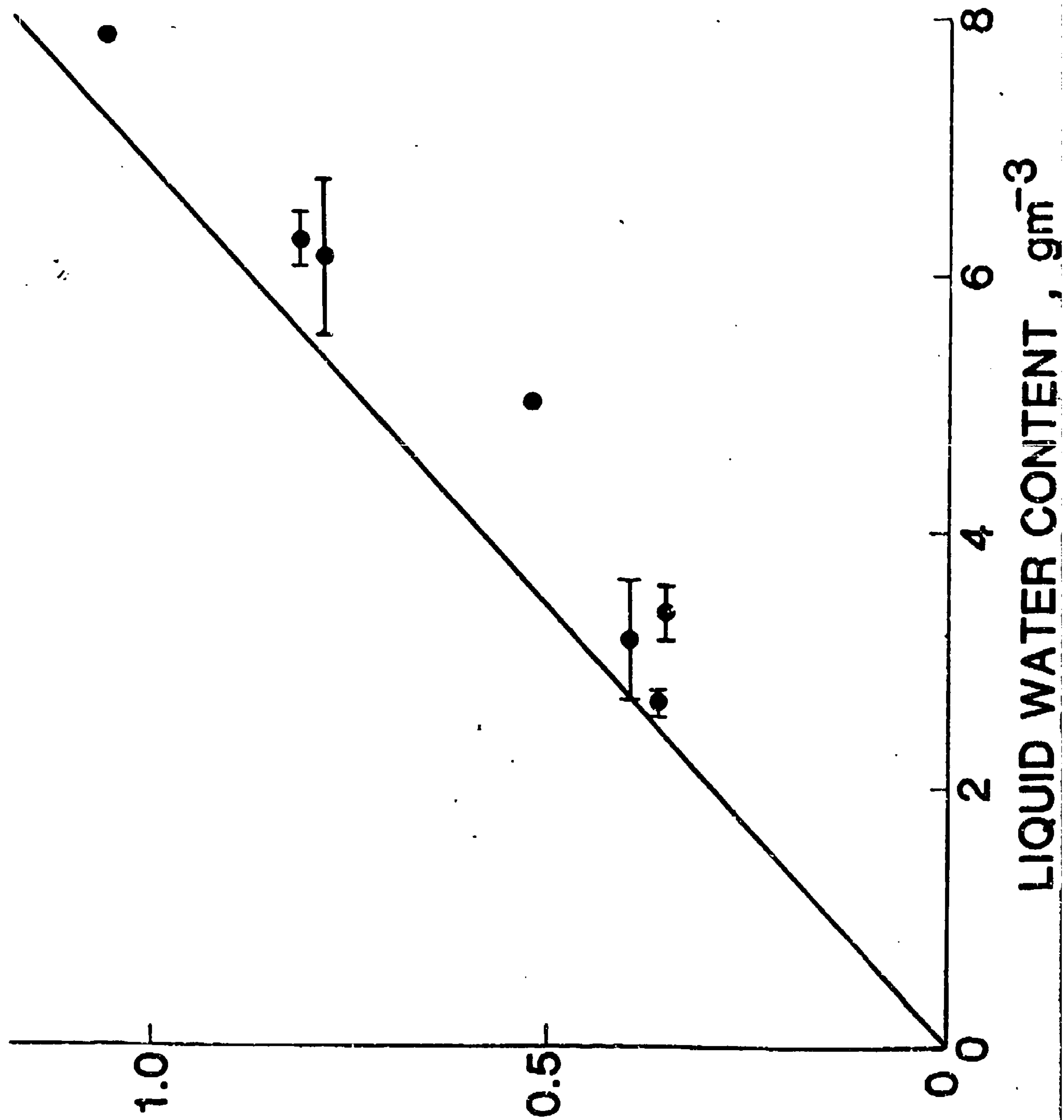
Fig. 1. Measured values of extinction coefficient σ_e (m^{-1}) and of liquid water content W (gm^{-3}) for laboratory cloud at wavelength $\lambda = 10.591$ μm.



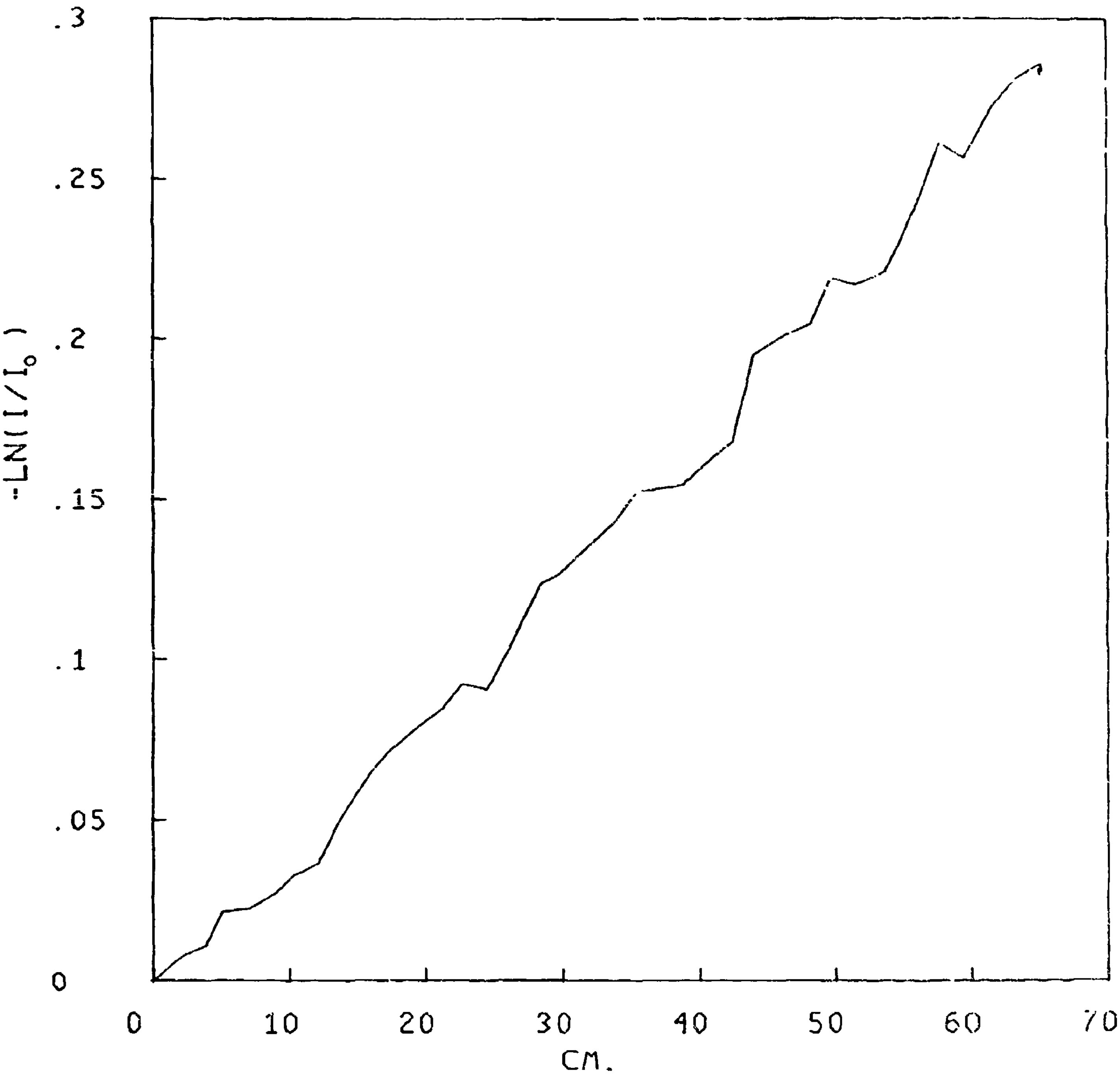
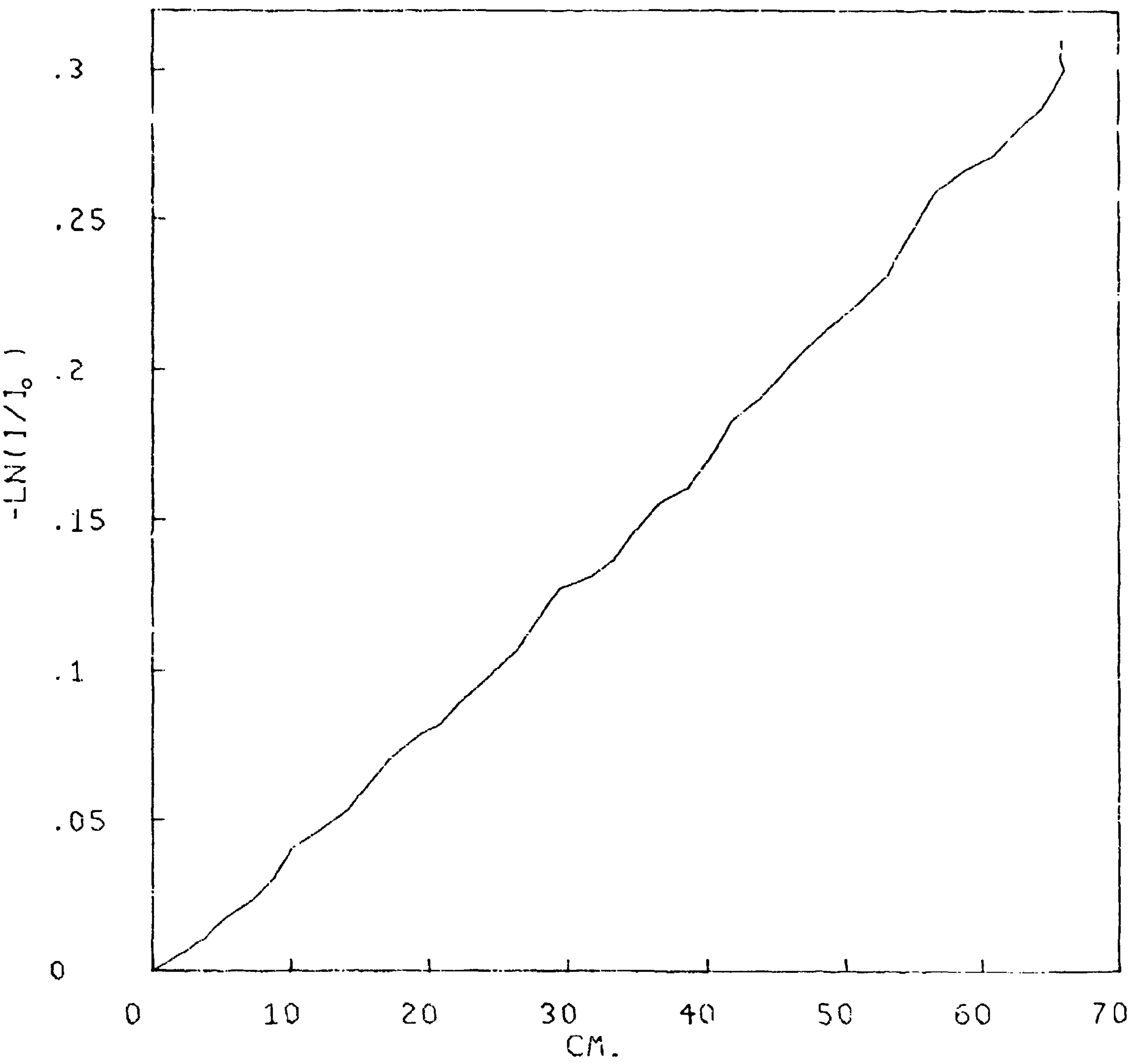


Fig.2 Optical depth ($\ell n\ I/I_o$) as a function of transmission path length in the laboratory cloud housing.

Fig. 3. Optical depth as a function of transmission path length in the laboratory cloud chamber.



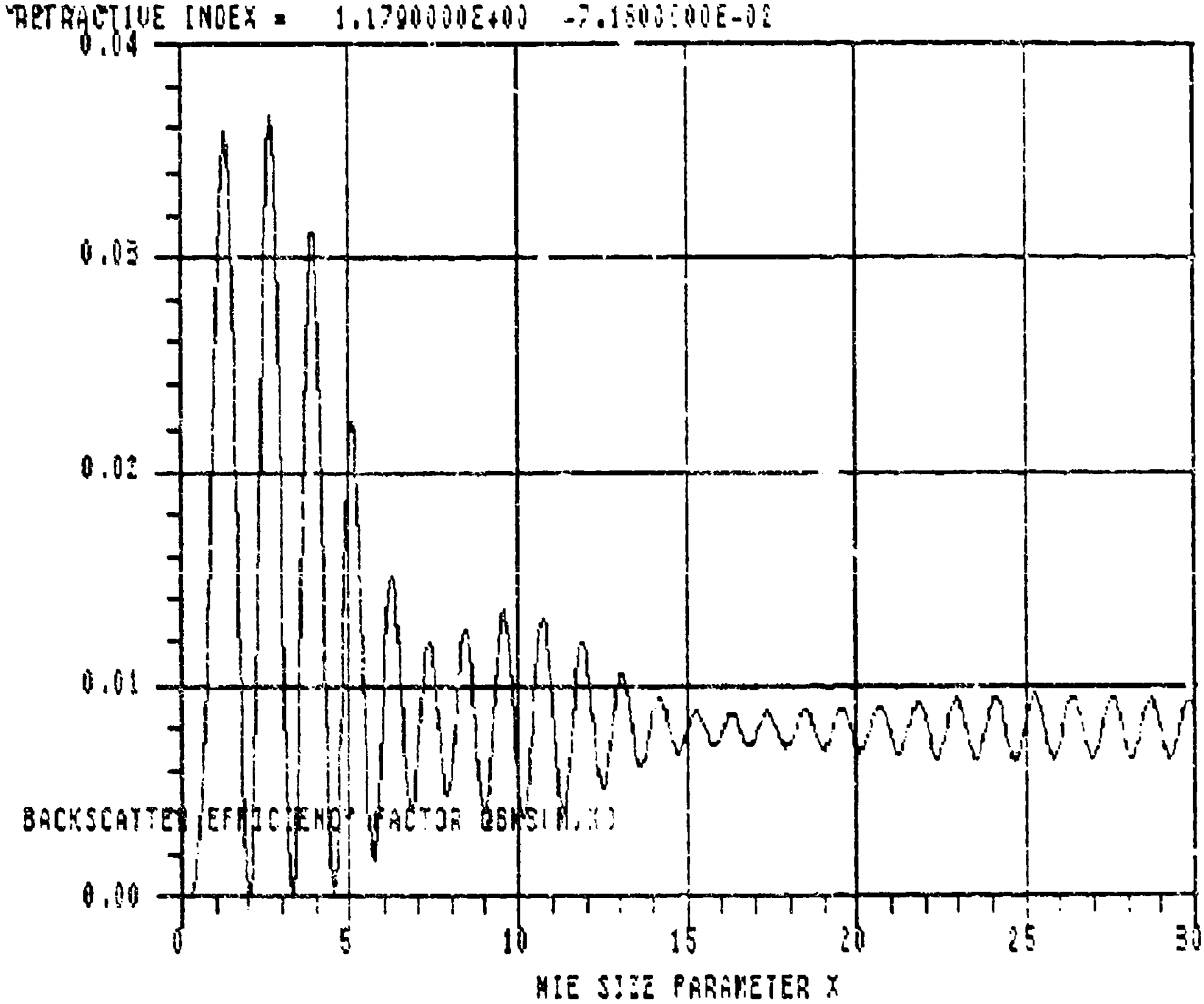


Fig.4. Normalised backscatter cross-section as a function of size parameter x for water at wavelength λ = 10.591 micrometres.

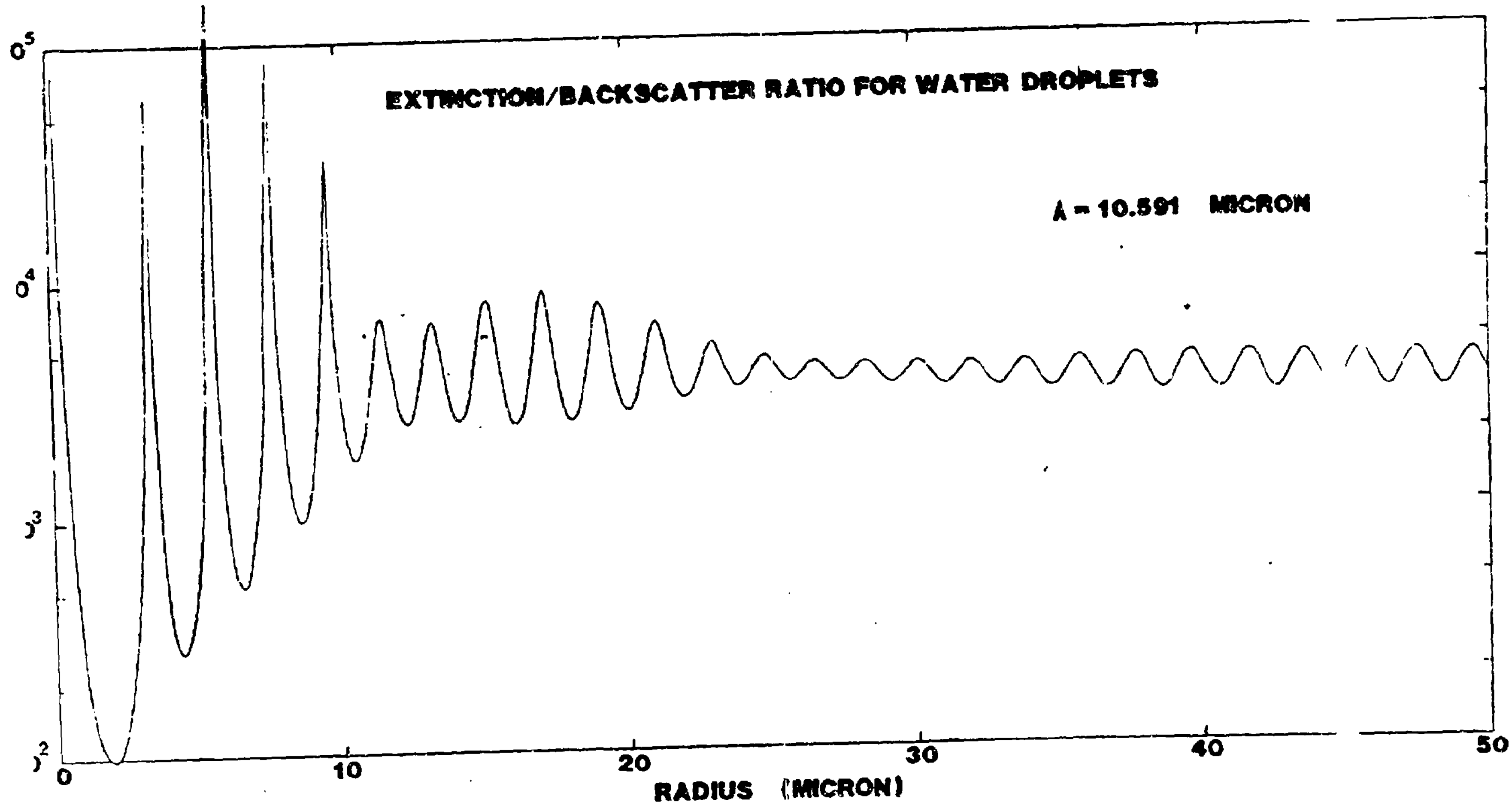


Fig. 5. Extinction to backscatter ratio for water droplets for wavelength $\lambda = 10.591\ \mu m$.