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AN INSTRUMENT FOR THE REAL-TIME MEASUREMENT
OF THE ABSORPTION COEFFICIENT OF AEROSOL PARTICLES*

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Recent studies have shown that large concentrations of graphitic carbon particles are found in the atmosphere in both urban and remote locations.\(^1\) These particles are produced in combustion and have a large optical absorption cross section, of the order of \(10 \text{ m}^2/\text{g}\). Their presence affects radiation transfer through the atmosphere, causing visibility degradation\(^2\) and possible changes in the regional or global radiation balance.\(^3\) The size of these effects depends critically on both the particle concentration and their single-scattering albedo,\(^4\) which is determined by the relative magnitude of the scattering and absorption coefficients. The scattering coefficient is easily measured by nephelometry.\(^5,6\) In this paper, we report on the development of a portable instrument for the real-time measurement of aerosol absorption.\(^7\) We have named this instrument the aethalometer, derived from the Greek word α θ αλςυ, "soot."

Measurements of the absorption coefficient of an ambient aerosol are difficult, mainly due to the small magnitude of this coefficient: typically, \(b_{\text{abs}} \approx 10^{-3} \text{ to } 10^{-6} \text{ m}^{-1}\). Measurement systems based on mirror-folded paths\(^8\) and photoacoustic techniques\(^9\) have been developed but require sophisticated

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apparatus that may make them inconvenient for routine use. The instrument that we have developed measures the attenuation of a light beam transmitted through the particles which are being continuously collected on a suitable filter. This method is based on the laser transmission technique.\textsuperscript{10} As predicted theoretically\textsuperscript{11} for a deposit of absorbing particles on a diffusely reflecting substrate, the laser transmission technique is sensitive only to absorption, a result confirmed by photoacoustic measurements.\textsuperscript{12}

The principle of operation of the aethalometer is illustrated in Fig. 1. A cellulose fiber filter (e.g., Millipore) is partially covered with a transparent mask so that air is drawn through only a small part of the filter, on which the particles are collected. The noncollecting portion of the filter covered by the mask is used as a reference. Light from a stabilized incandescent lamp passes through a 350-nm bandpass filter and is then directed by a quartz light guide to uniformly illuminate the collecting and reference areas of the cellulose filter. The light transmitted through these two portions of the filter is incident on optical fibers set into the filter support, giving signal and reference beam intensities of $I$ and $I_0$. The fibers conduct these beams to silicon detectors coupled to a logarithmic ratiometer.\textsuperscript{13} The voltage output from this unit is proportional to the optical attenuation, defined as $A = -\ln(I/I_0)$, which is due to the collected absorbing particles.

If the instantaneous absorption coefficient of the aerosol in the air column being drawn through the filter is $b_a(x,t)$, and $v$ is the airstream velocity at the filter face, then the attenuation at time $T$ due to the deposit on the filter will be

$$A(T) \propto \int_0^T b_a(x,t) \cdot v \, dt.$$
Differentiation of the voltage proportional to $A(T)$ will then yield a measure of $b_a(x,t)$. Since the rate of increase of $A(T)$ is rather slow (typically 0.1% per minute), we use digital methods to perform the differentiation. At selected time intervals, the signal is digitized and stored. This result is subtracted from the previous measurement, giving a difference proportional to the average of the absorption coefficient during the averaging time interval. The output is available in digital form for further processing and is also converted back to an analog signal for chart recorder display.

The instrument was calibrated by operating it in parallel with a sampler collecting aerosol particles on prefired quartz fiber filters. It has been shown that the dominant absorbing species in urban aerosols is graphitic carbon,\textsuperscript{14} which may be measured on quartz fiber filters by a combined solvent extraction and thermal analysis technique.\textsuperscript{15,16} Comparison of the two results enabled us to calibrate the aethalometer output in terms of a concentration of graphitic carbon in micrograms per cubic meter. To calculate the absorption coefficient of this material in suspended form, we used an absorption cross section of $10 \, \text{m}^2/\text{g}$, which is compatible with reported theoretical\textsuperscript{17} and experimental results.\textsuperscript{18,19} We then employed the convenient relation [absorption coefficient (units $10^{-6} \, \text{m}^{-1}$)] = [concentration (units $\mu\text{g}/\text{m}^3$)] x [cross section (units $\text{m}^2/\text{g}$)]. In the present configuration, the estimated minimum detectable increment in attenuation corresponds to an incremental loading of $10 \, \text{ng/cm}^2$ of graphitic carbon on the filter. With an airstream velocity of 2.5 m/sec at the filter face, the sensitivity may be represented by a value of the product [minimum detectable absorption coefficient] x [averaging time] of $4 \times 10^{-4} \, \text{sec/m}$. Using an averaging time of 5 minutes, we are able to detect a graphitic carbon concentration of $0.13 \, \mu\text{g}/\text{m}^3$, corresponding to an absorption coefficient of $1.3 \times 10^{-6} \, \text{m}^{-1}$. 
Figure 2 shows an example of the aethalometer output, taken when sampling ambient air in Berkeley. It is clear that there is a strong diurnal variation of the absorption coefficient that may be linked to the movement of air masses as well as variations in emissions. In addition, we can see events that may be attributable to the passage of individual heavy diesel vehicles on a lightly travelled road some 100 yards from the sampling location. The instrument was used in the field during the EPA visibility study in Houston, Texas, in September 1980. Figure 3 shows a result from that study, where the output has been smoothed with a time constant of approximately 20 minutes. Also shown on this figure are the simultaneous nephelometer measurement of the scattering coefficient and the calculated single-scattering albedo. It is clear that in this case the magnitudes of the scattering and absorption coefficients are not in constant proportion to one another and that the development of a real-time instrument such as the aethalometer described above is necessary for the determination of this variation.

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References


13. Optical multimeter, Model 22XL, manufactured by Photodyne, Inc., Westlake Village, California.


Figure Captions

Figure 1. Block diagram of instrument. Optical and aerosol collection components: A, light source; B, 530-nm bandpass filter; C, quartz light guide; D, transparent mask; E, filter with particles collected on portion underneath hole in mask; F, filter support with optical fibers set in; G, flow meter. Electronic system components: 1, silicon photodetectors; 2, logarithmic amplifiers; 3, difference amplifier giving output proportional to $\ln(I/I_0)$; 4, A/D converter; 5, storage and subtraction; 6, variable timebase; 7, D/A converter.

Figure 2. Absorption coefficient versus clock time at Lawrence Berkeley Laboratory, 1 September 1981. Individual events (e.g., at 1630) may be due to the occasional passage of heavy vehicles on a nearby service road.

Figure 3. Smoothed data from Houston, Texas, 13 September 1980. Lower curves show absorption coefficient measurement by this instrument and scattering coefficient measured by a conventional integrating nephelometer, versus clock time. The upper curve shows the variation in single-scattering albedo $\omega = b_s/(b_s + b_a)$. Note that the strong variations in absorption and scattering occur at different times of the day. The absorption peaks may correspond to local and regional vehicular emission patterns, while the scattering peak occurs later in the day. Variations in the albedo are significant, although somewhat reduced by the unusually large magnitude of the scattering coefficient.
Aerosol inlet

To vacuum pump

Signal

Reference

\[ \text{Signal} \rightarrow \frac{1}{A} \rightarrow I \]

\[ \text{Reference} \rightarrow \frac{1}{A} \rightarrow I_0 \]

\[ \ln I_o \rightarrow 2 \]

\[ \ln I \rightarrow 3 \]

\[ \text{Outputs:} \]

Analog

Digital

\[ 7 \rightarrow 5 \rightarrow 4 \rightarrow 3 \]

\[ 6 \]

Figure 1

XBL 826-722
Figure 2
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