LASER REMOTE SENSING OF MARINE SEDIMENT LOAD AND ALGAL PIGMENTS:

LABORATORY EXPERIMENTS

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The fluorescence spectrum for natural waters contains several features which may be used for remote sensing of dissolved and suspended materials. Figure 1 shows the fluorescence emission spectrum for an estuarine water sample excited by an argon laser at 514.5 nm. The features of interest are: (1) scattering at the laser wavelength by particulates (Mie), (2) fluorescence from the pigments chlorophyl a and phycoerythrin, (3) Raman scattering by water, and (4) fluorescence by dissolved organic matter. These intensities increase with the concentration of the corresponding material and decrease with attenuation. Note that since the concentration of water is constant the Raman intensity provides a direct measure of attenuation.

The optical models relating intensities and concentrations are shown in figure 2. The first expression is the general case for laser backscatter assuming single scattering. The high altitude approximation, altitude >> remote sensing depth, allows the simple form shown rather than a nonintegrable integral form. Neither assumption significantly affects the relation between intensity and concentration. The symbols used are:

P_o - laser output power
A_c - area of collecting telescope
n - refractive index of water
h - altitude
N - concentration
σ^* - cross-section for backscatter
γ - effective attenuation coefficient
K - constant
α - beam attenuation coefficient
a - absorption coefficient
b - scattering coefficient

The expression for the Mie and Raman intensities results directly from inserting the appropriate subscripts. In the Mie case the change in intensity with increasing concentration is not simple since both $N\sigma$ and γ increase. In general we expect a near linear relation at low turbidity changing to saturated condition at high turbidity. The Raman intensity varies inversely with attenuation only, since $N\sigma$ is constant for water. The final two expressions, Mie/Raman and fluor/Raman, use the Raman-attenuation relationship to remove the attenuation effect. The ratio of attenuation coefficients at the various wavelengths is approximately constant or at worst slowly varying, so that we expect the Raman intensity to indicate attenuation, Mie-to-Raman to indicate suspended sediment (total suspended solids), and fluorescence-to-Raman to indicate the concentration of the fluorescing material.

Laboratory experiments have been conducted to compare intensities and concentrations as indicated above. The apparatus shown in figure 3 was designed to provide a reasonable simulation of the remote sensing situation with natural samples brought back to the lab. Spectra are recorded with an Optical Multichannel Analyzer (OMA) which allows rapid recording on magnetic discs and subsequent algebraic manipulation. The detector is a silicon-intensified target vidicon tube preceded by an image intensifier. Spectral resolution is 2.5 nm. In our sampling procedure we emphasize returning the samples within 4 to 6 hours of collection and treating them so as to minimize biochemical stress. Samples for chemical and optical analysis are taken from the measuring tank immediately following the fluorescence measurement.

Figure 4 shows a typical recorded spectrum and the problem of overlapping peaks. The OMA allows subtracting the fluorescence due to Dissolved Organic Matter (DOM) and then integration of the remaining peaks to obtain true intensities. Figure 5 shows how the DOM spectrum is obtained by analysis of a filtered sample. The OMA normalizes this DOM curve in the region between 514.5 and 550 nm, judged to be free of Mie and phycoerythrin signal, and subtracts to produce the DOM corrected curve. This also determines the DOM intensity. Figure 6 shows the same procedure applied to a river sample containing a high level of DOM and no phycoerythrin.

Prior to studying natural samples, validation experiments were performed to check the expected behavior of the optical models. Figure 7 shows the results of a test in which a clay was added to distilled water and the intensities compared to attenuation. The various relations are as expected.

As a more rigorous test using natural samples a 1-day experiment was performed during September 1980. A wide variety of water types was included from fresh water in the James River to high salinity coastal water at the mouth of the Chesapeake Bay. Figure 8 shows the location of the sample sites. In addition, a few samples were made up by mixing ocean and river water. Figures 9 through 13 show the results of the intensities and chemical/optical comparisons. Inverse Raman intensity vs. attenuation gives excellent agreement--this is the most consistent and noise-free of all the comparisons. The Mie/Raman vs. TSS and chlorophyl/Raman vs. chlorophyl **concentrations are also** good. The DOM/RAM vs. DOC shows the worst comparison. This is probably caused by a nonfluorescing contribution to DOC. From our experience DOM fluorescence is due to humic material in land runoff. This is illustrated by the much better comparison of DOM/RAM vs. DOM absorption.

For one of the samples fluorescence was recorded using two different excitation wavelengths, shown in figure 14. This illustrates two considerations in choosing the exciting wavelength: (1) the variation of the chlorophyl excitation cross section with wavelength and (2) the overlap of spectral peaks. DOM and chlorophyl intensities are difficult to obtain using 532-nm excitation because of shift in the Mie and Raman peaks relative to the fixed fluorescence spectra of chlorophyl and phycoerythrin. Similarly for an excitation wavelength much below 510 nm the Raman and phycoerythrin peaks will begin to overlap. A wavelength of about 520 nm is optimum for good resolution of all features.
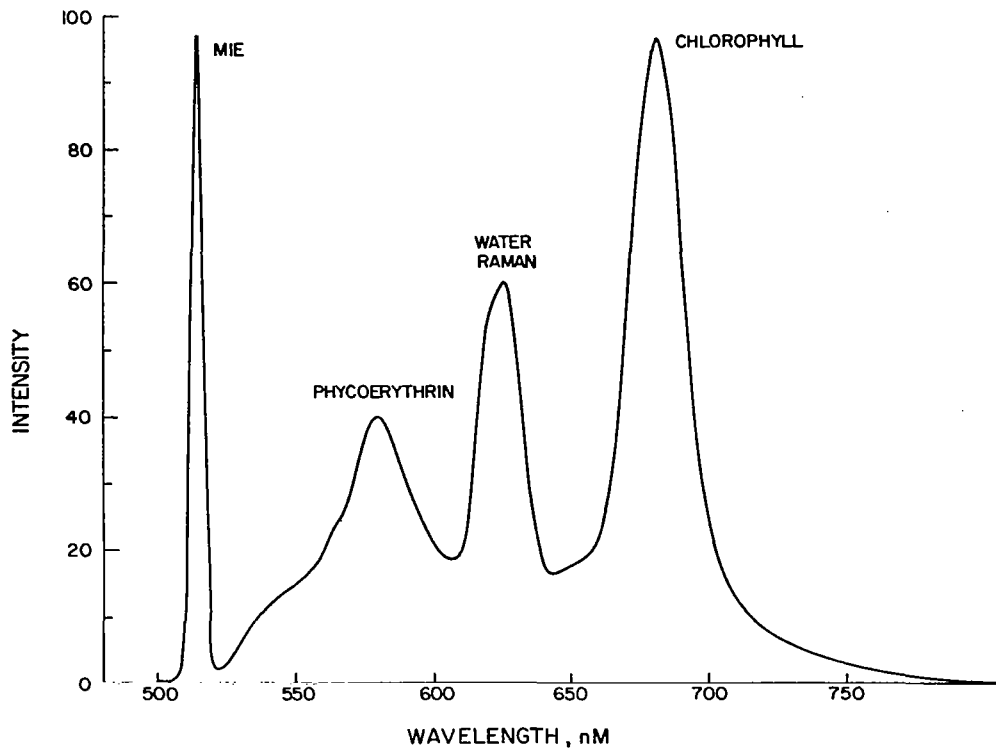
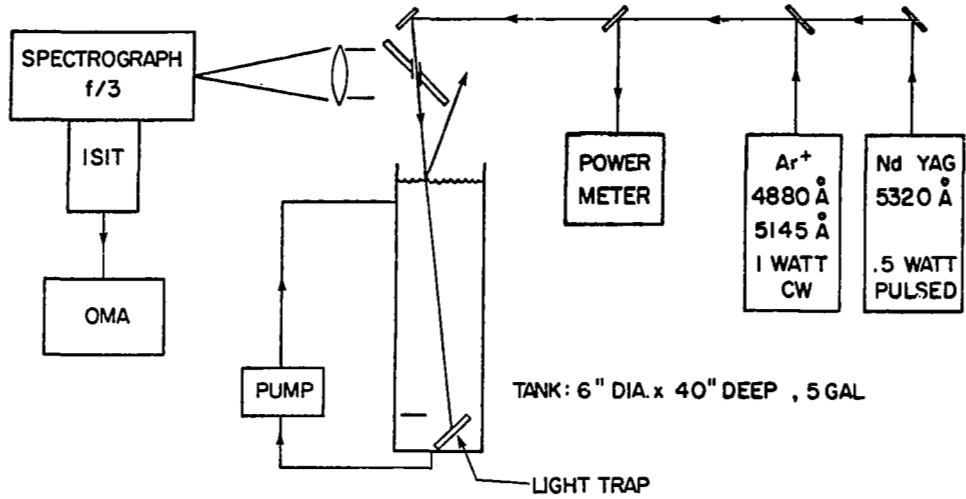Figure 1

OPTICAL MODELS FOR LASER FLUOROSENSOR
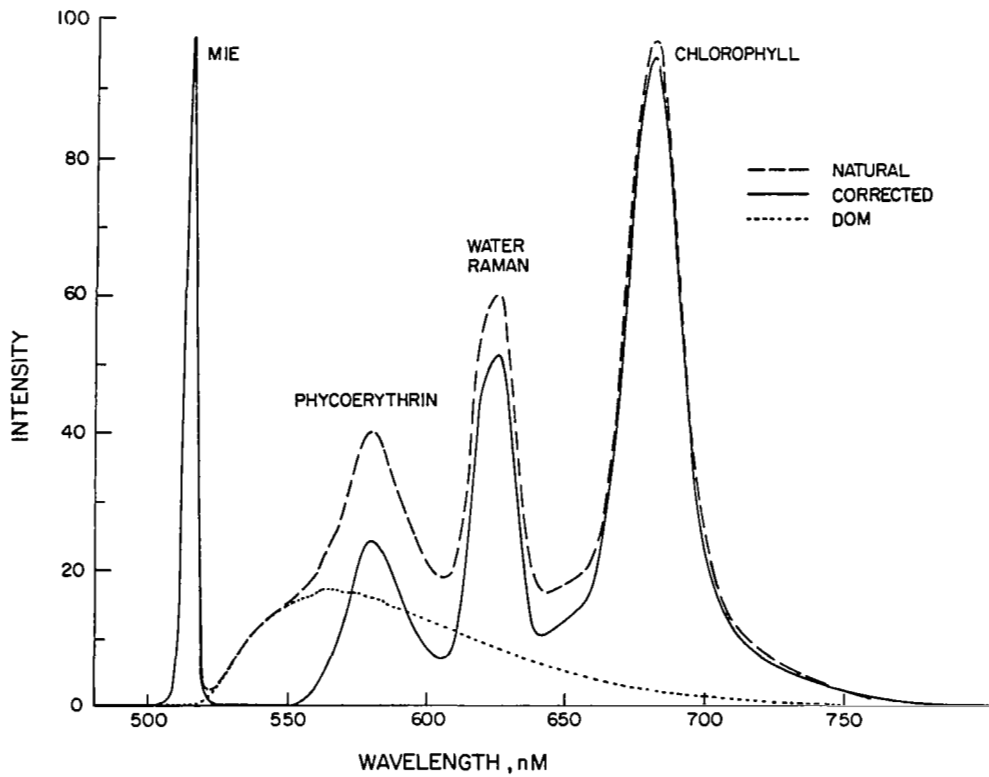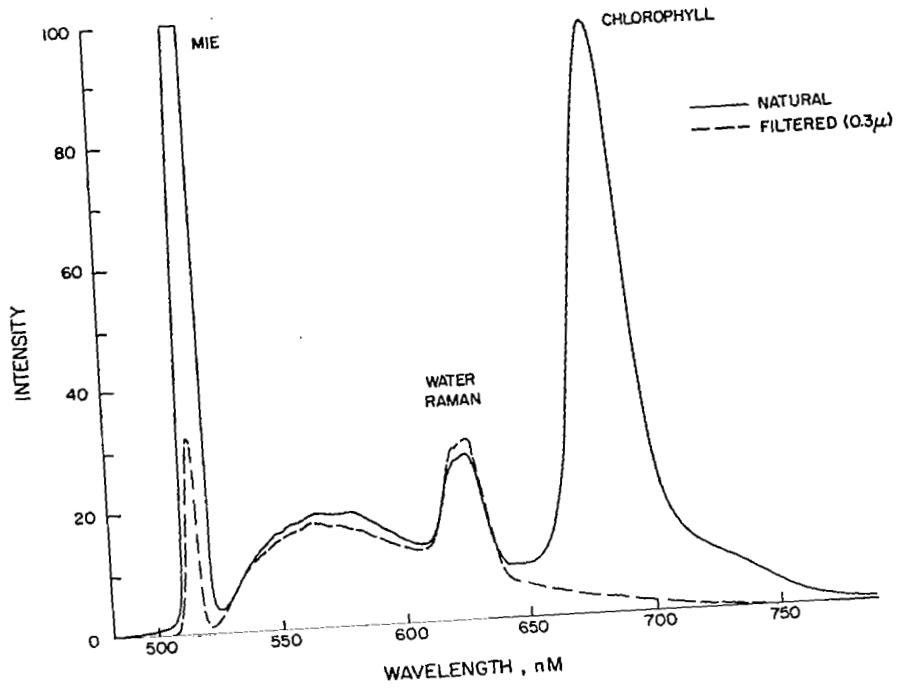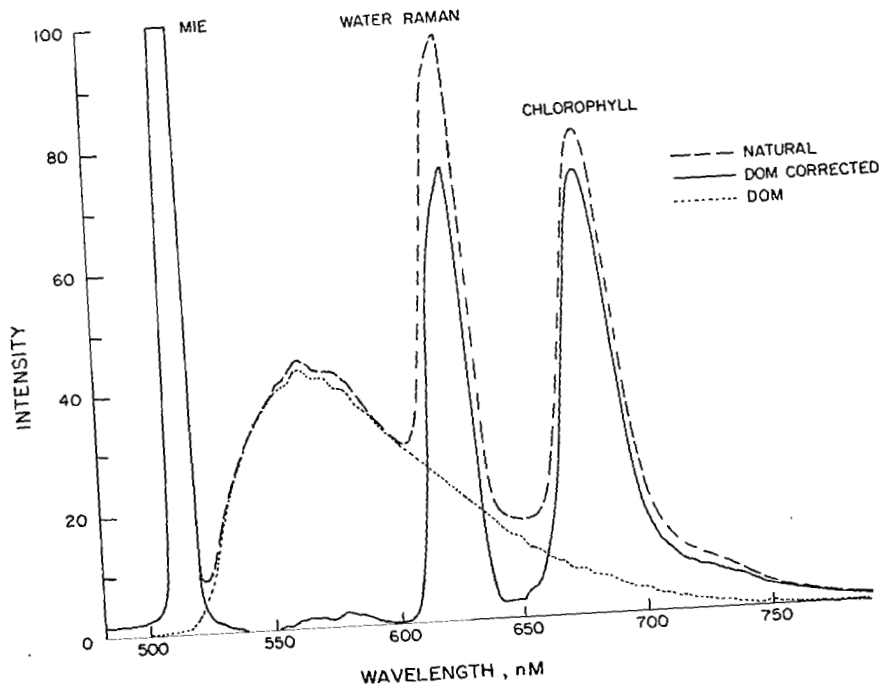

Figure 2

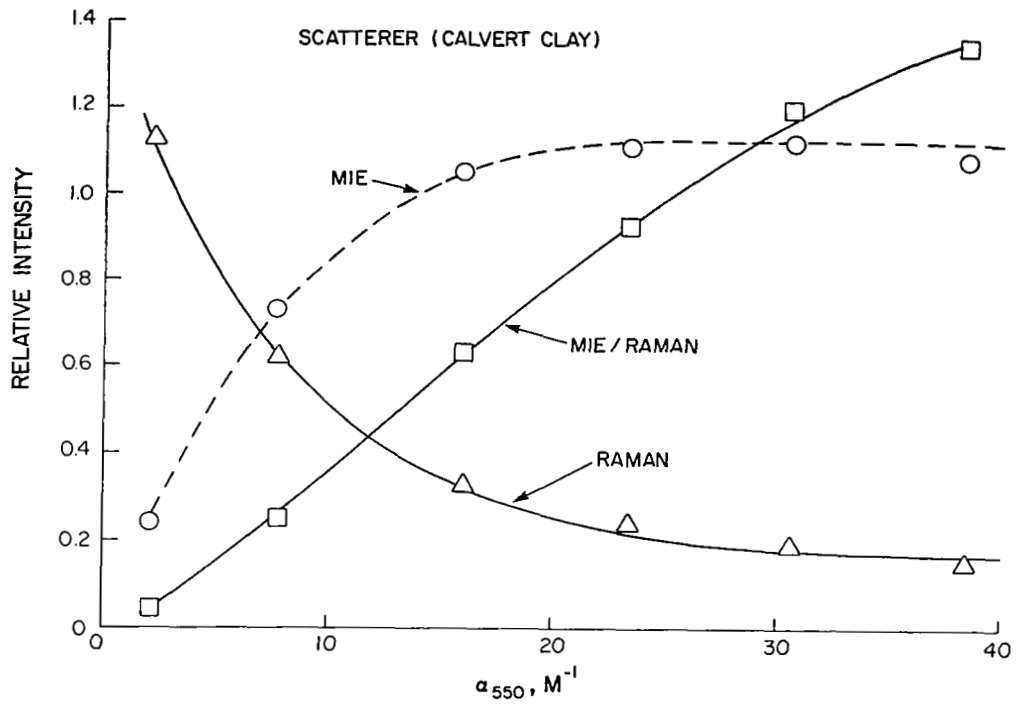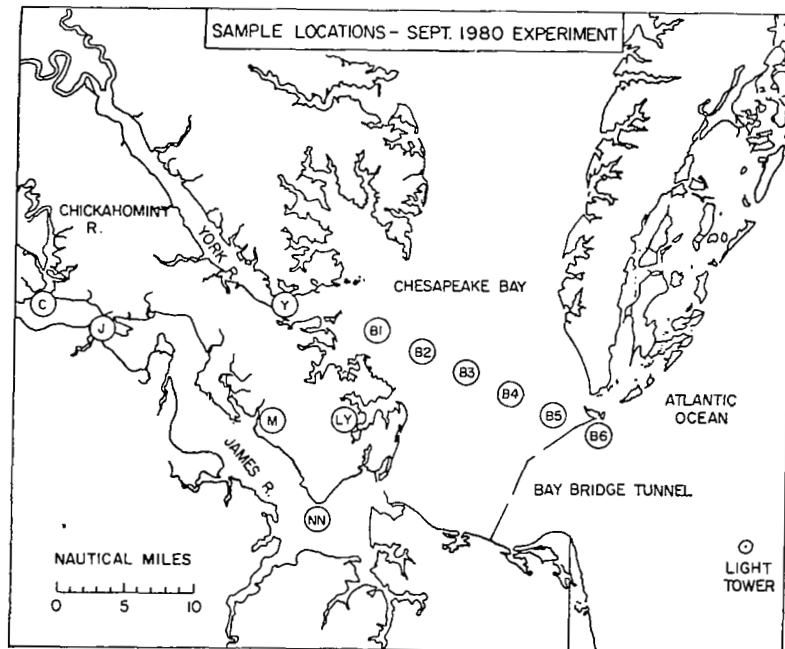# LABORATORY FLUOROSENSOR

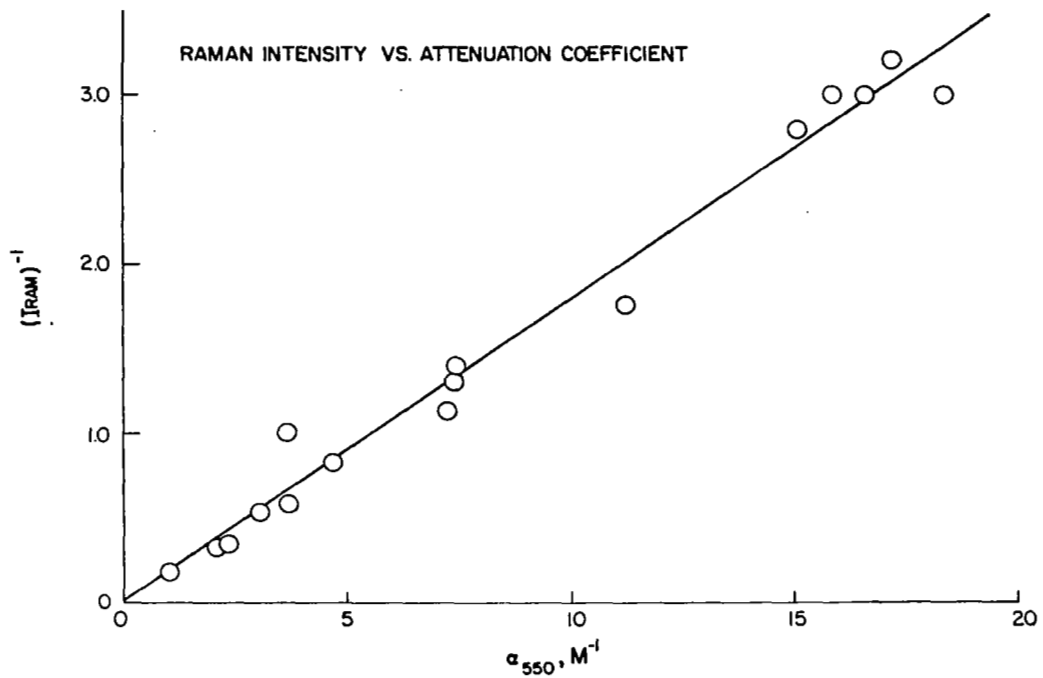Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9
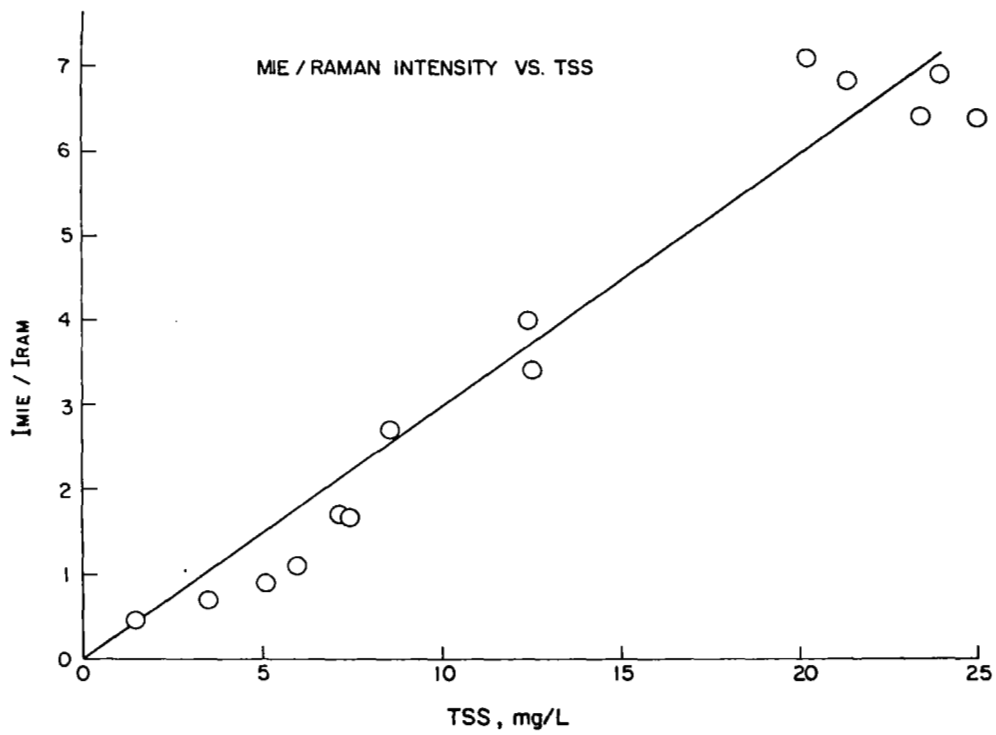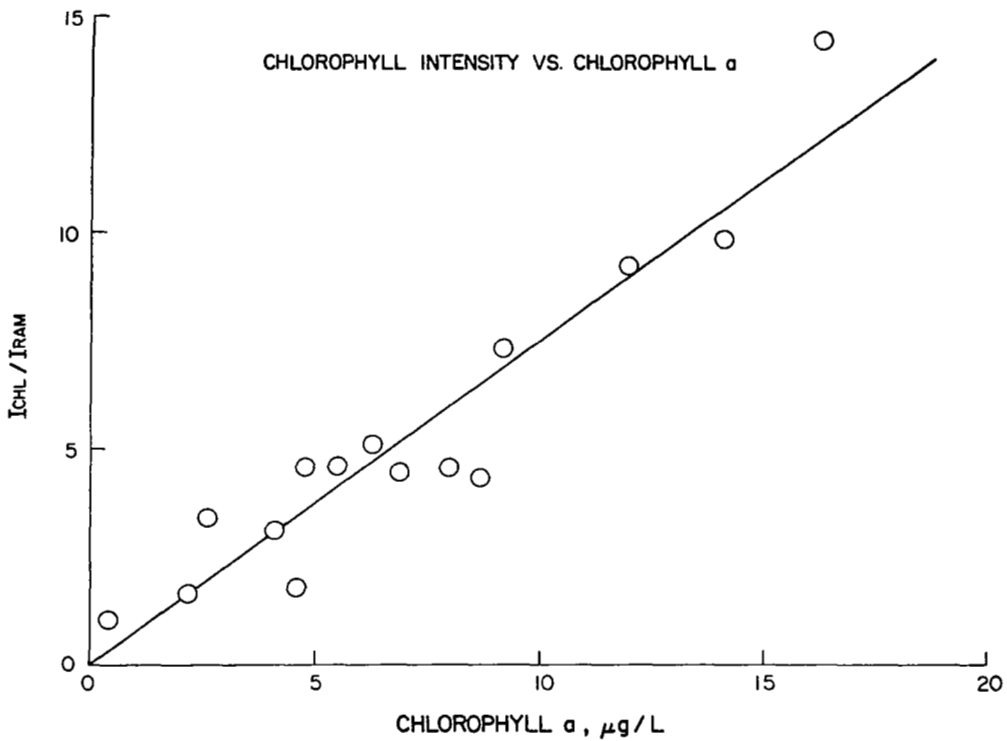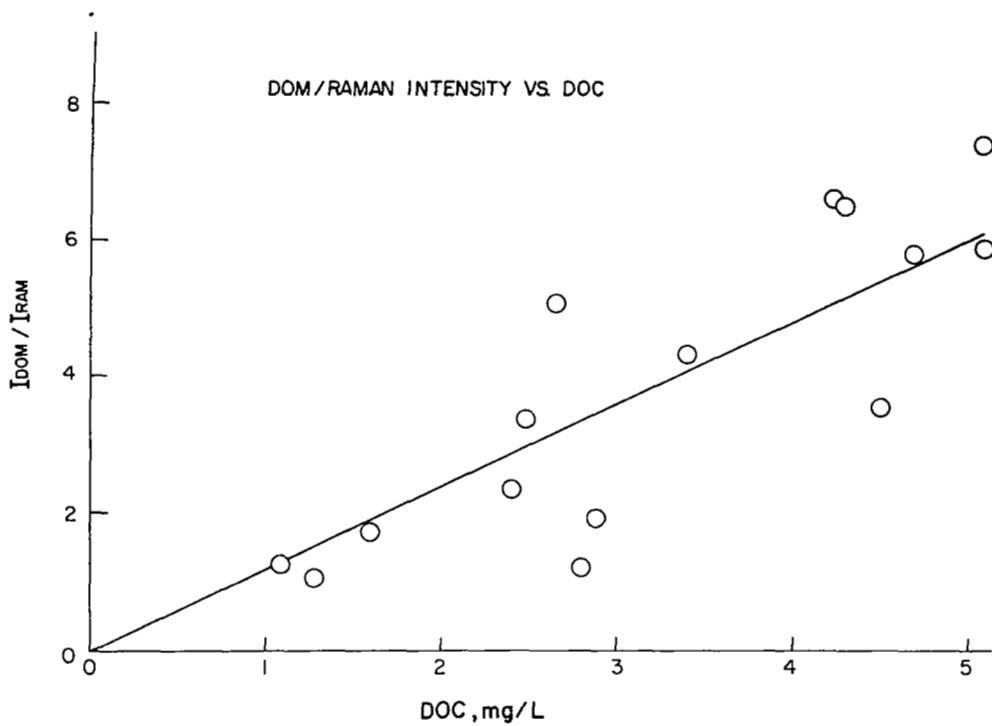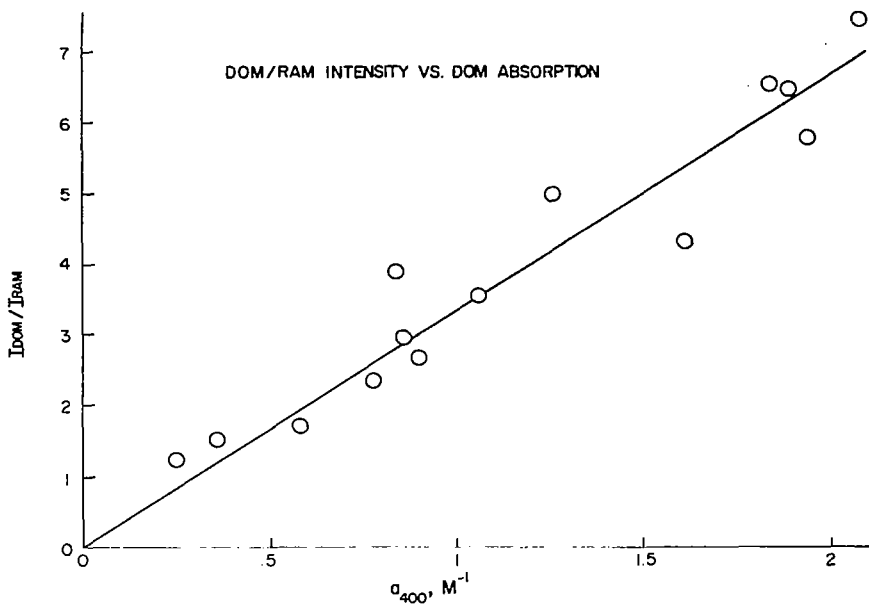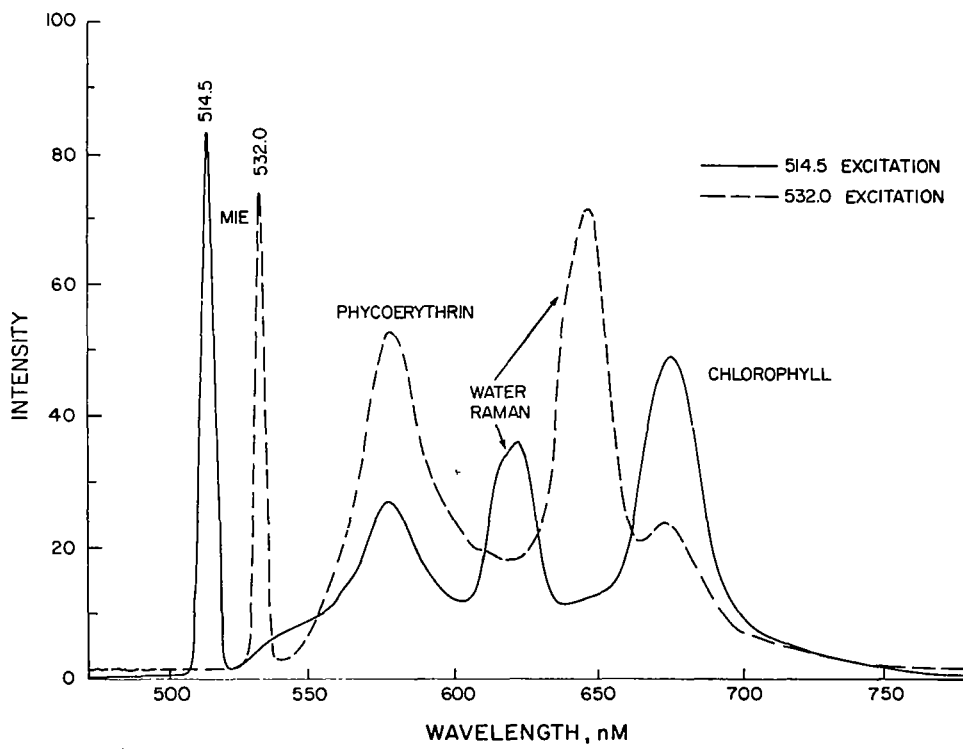

Figure 10

Figure 11

Figure 12

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Figure 13

Figure 14