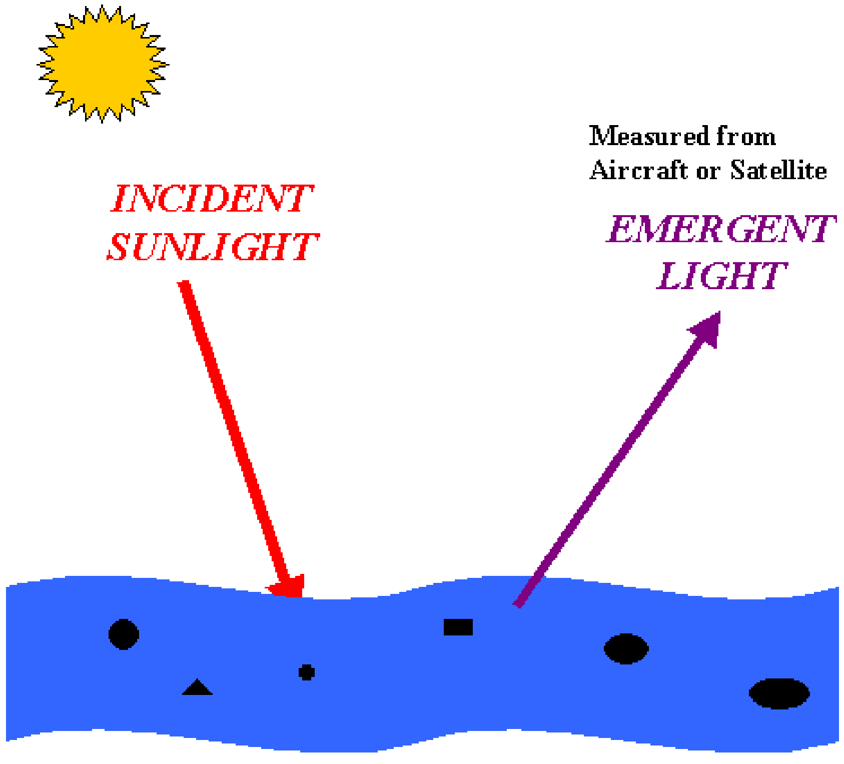
■ Example 4: Measurements of Light to estimate the Quality of Water

(a) Description of the problem

Sunlight, whose spectral properties are known, enters a natural water body. The spectral character (how it varies with wavelength) of the sunlight is then altered,depending on the absorption and scattering properties of the water body,which of course depend on the types and concentrations of the various constituents of the particular water body.



OBJECTS IN WATER MAY ABSORB OR SCATTER LIGHT

Part of the altered sunlight eventually makes its way back out of the water, and can be detected from an aircraft or satellite.If we know how different substances spectrally alter sunlight then we can hope to ***deduce from the altered sunlight what substances must have been present in the water,and in what concentrations.***

(b) Some aspects of/ approaches to solving the problem:

A fundamental aspect of this problem has to do with ***transfer of radiation***.
A large amount of work has been done on the "theory of radiative transfer" so one possibility is to apply the results of this.

(b.1) Using the equations of radiative transfer:
It turns out that radiation transfer in any medium (including water) is governed by a rather complicated integro-differential equation.

To make things somewhat tractable various simplifying assumptions can be made - for example,
- assume the water body is homogeneous
- assume that absorption and/or scattering does not vary with water depth
- assume that the particles in the water have simple shapes (e.g. spherical)

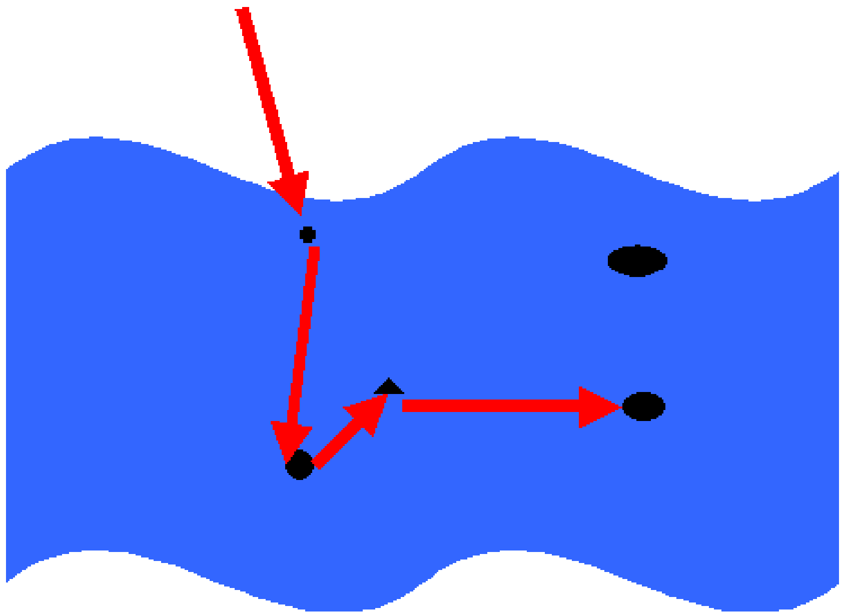
Still, the mathematical problem remains formidable. Two ways of attacking it are

(I) Approximate the equations using a completely numerical approach - replacing integrals by sums, etc -. The result is a complete approximation to the underwater light field, including of the emergent light.

(II) Use known "exact" solutions that describe ***just the emergent light***. The mathematics is quite cumbersome and gives a good opportunity for use of symbolic computation tools.

(b.2) Using Monte Carlo simulation:
In general, the aim is to use Monte Carlo simulations of photon propagation to establish semi-empirical linkages between properties of the radiation field and inherent properties of the attenuating medium (the water).

The approach may be sketched as follows:
"The geometric path followed by a single photon of light, and the series of its lifetime encounters with scattering and/or absorption centers residing in the water are best described in terms of a ***random process*** controlled by the nature of the individual photon and the nature of each individual scattering and absorption center.



The inherent optical properties of the water column provide probability distributions that can define the distance between successive interactions, whether that interaction is scattering or absorption, and the directionality of scattering interactions.

Monte Carlo simulations follow the propagation of a large number of photons, considered individually, through an imaginary water column possessing a pre-selected set of optical properties.

The statistical accuracy of the Monte Carlo method is directly related to the number of individual photons tracked (oftimes millions).