transmittance e^{-Kz} of a given layer of water ($z = 10$ meters in this case) as a function of wavelength. While it would be generally more desirable and more directly useful to simply plot the K-function for $H(z,-)$ as a function of λ, even as they stand, the graphs give an informative picture of the five general types of oceanic water encountered by Jerlov in his long series of careful studies of Atlantic and peripheral waters. These graphs could be of even greater service if someday they or their kind are supplemented by similar plots of α as a function of λ, along with σ, as a function of both θ and λ, if the patience and funds for such a pioneering effort could ever be assembled. The rationale behind these observations will be outlined in the following section.

1.7 Some General Modes of Classification of Natural Optical Media

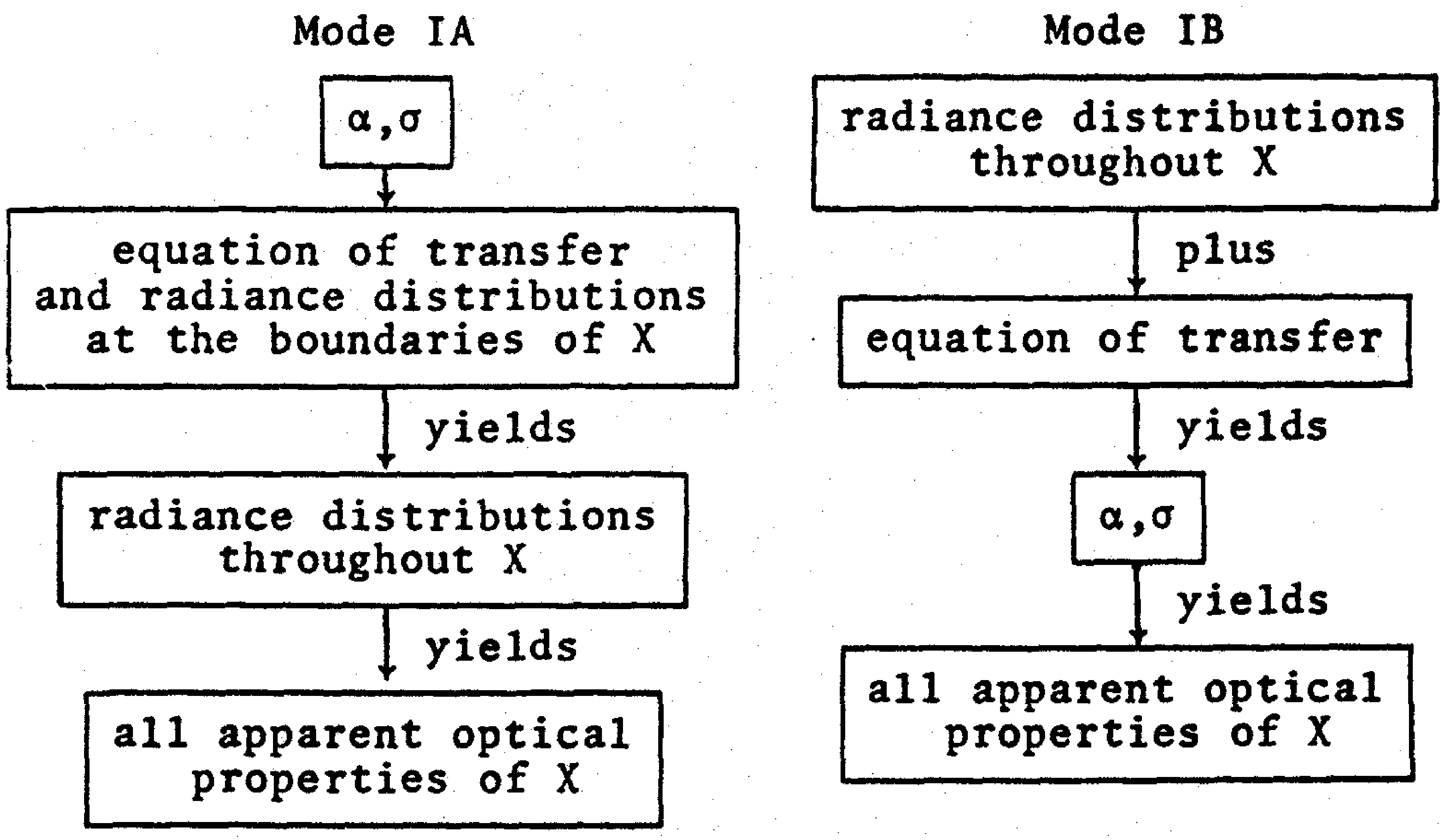
Our studies in the preceding sections, especially those in the section just concluded, lead us to seek out those of the manifold optical properties used in the mathematical models of light fields in natural hydrosols that are fundamental and most useful. This problem has no simple solution, and indeed has different answers depending on one's view of the role of hydrologic optics in the study of natural waters. If one were a mathematician interested primarily in the intricate geometrical relations among the radiance distributions and their connections with the physics of the medium then, unquestionably, the inherent optical properties α and σ as functions of position and wavelength (or equivalently α and a) constitute the only scientific answer to the query. If one were interested mainly in engineering calculations leading to estimates of the visibility of submerged objects in natural or artificial light fields then, equally clearly, the full spatial and spectral measurement of the properties α and K would suffice for most such purposes. On the other hand, a biologist interested in the problem of photosynthesis may find it possible to conduct a large portion of his work using only the volume absorption function a or only the diffuse attenuation function K. If one were a physicist or chemist concerned mainly with the analysis of water for the detection of certain dissolved and suspended substances, then quite likely σ and α (or equivalently σ and a) would suffice, but for vastly different reasons than those given by the mathematician mentioned above. For the mathematician would use α and σ to compute $N(z,\xi)$ at each depth z and for each direction ξ, while the physicist or chemist would use α and σ to yield concentrations of solutes and suspensoids in the irradiated sample of the hydrosol.

Modes of Classification

In view of the preceding observations, several alternate modes of classification of natural optical media are possible. We now list the main modes of classification and indicate how much information about the hydrosol is inherent in each.

Mode IA *Specifying* α,σ *as functions of position, direction (for* σ*) and wavelength through the medium* X.

The measurements of α,σ are envisioned here as done by means of specially designed α-meters and σ-meters (cf. [78]). The deductions that are possible using this mode are indicated schematically as follows under the column labeled "Mode IA":



The procedure by which the radiance distributions throughout the medium are obtained from α, σ, the equation of transfer, and the boundary lighting conditions on the hydrosol is now a well established procedure which may take several alternate forms. The main techniques for such calculations are summarized in Chapters 4, 5, 6, 7 and 8 below, and in Part Three of Ref. [251]. The determination of the apparent optical properties from radiance distributions proceeds as outlined in (23)-(26) of Sec. 1.6.

Mode IB *Specifying radiance distributions throughout* X *as functions of wavelength.*

This mode of classification is extremely fruitful, for as the deduction diagram for Mode IB shows, this information will yield all the inherent and apparent optical properties of the medium. Table 7 of Sec. 1.6, except for α, s and a, was constructed using this mode of classification. The manners in which the inherent optical properties α, s and a of a medium are forthcoming from radiance distribution measurements are explained in Chapter 13. Modes IA and IB are in principle mathematically equivalent modes of classification and rank highest in the hierarchy of possible modes of classification as regards completeness of information about the hydrosol studied.

Mode II *Specifying* $H(z,\pm)$ *and* $h(z,\pm)$ *as functions of position and wavelength throughout* X.

From the four irradiances of Mode II comes the set of all apparent optical properties discussed in Sec. 1.6. An extraordinary amount of information is forthcoming from such a mode of classification when it is realized that we are replacing the radiance distribution $N(z,\cdot)$ at each depth z by just four numbers $H(z,\pm)$, $h(z,\pm)$ at that depth. A number of deductions of the relations among the inherent optical properties s and a and a wealth of subsidiary properties are possible from a carefully conducted Mode II classification. The bases for these deductions are explored in Chapters 9, 10 and 13.

It may seem odd to suggest modes of classification which are comprised only of radiometric documentations of light fields. However, when one reflects on the matter, it becomes clear that this is precisely how all the usual apparent optical properties are found in the first place! Therefore if an investigator accompanies the listing of the deduced optical properties, of current interest, with a listing of the complete $H(z,\pm)$ and $h(z,\pm)$ measurements (or preferably the $N(z,\xi)$ measurements) from which he made his deductions, he thereby makes available to subsequent investigators potential information he is presently uninterested in or which his technology may not yet be able to extract. Imagine, for example, if scientists in Galileo's time documented the light fields by means of radiance distributions, however crudely, we would now be able to extract information about those hydrosols that the original investigators hardly could conceive of. Flights of fancy to one side, the reader should perceive the underlying intent of this observation and its pertinence to Mode II.

Mode III *Specifying* α *and* K *as functions of position and wavelength throughout* X.

The collection of α and K measurements is here envisioned as made by a single instrument assembly so designed as to simultaneously measure α and K as it is lowered into and moved about in the optical medium. For example, such a device, designed by R.W. Austin of the Visibility Laboratory, University of California [7], has been used in coastal surveys by the U.S. Oceanographic Office.

By a judicious choice of near-surface radiance distributions and by virtue of the near-universality of shape of the σ curves (cf. Fig. 1.73) one may be able to estimate $N_*(z,\theta)$, using (50) or (61) of Sec. 1.4 with the K values supplied by Mode III of the classification scheme. Then with (14) of Sec. 1.3 and the α as found by Mode III, excellent estimates may be obtained of the radiance distributions within a medium probed in a Mode III fashion. Once these radiance distributions are obtained, then we are in effect in possession of a Mode IB wealth of knowledge, provided the simple model for radiance fields is applicable.

Further members are possible in the preceding hierarchy of modes of classification of natural hydrosols. However, a proliferation of such modes at this time is not desirable, as it would detract attention from the only mode really worth considering in the establishment of a science of hydrologic optics, namely Mode I in either of its equivalent guises A or B. However, this ideal may not soon be reached, and accordingly the two lesser but yet extremely useful modes of classification are included in our present survey. Finally, *whenever possible and in the interests of consistency and completeness, measurements in the preceding modes should be done in the polarized light context and also as a function of time, if such is indicated by the physical (or biological) state of the medium* (cf., Sec. 13.6, 13.11).

A complete theoretical analysis and classification of the optical properties in arbitrary optical media is made in Sec. 9.6.

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1.8 Colorimetric Radiative Transfer

An interesting application of radiative transfer theory can be made to the studies of the apparent colors of objects located within media that scatter and absorb radiant energy in a selective fashion. The application of the principles of radiative transfer to such studies is straightforward and requires no new concepts to be introduced into the theory beyond those we have been considering. For this purpose we need only adopt the well-known standard C.I.E. (*Commission Internationale de l'Eclairage*) color coordinate system, within which any spectral sample of radiant flux may be located and assigned a unique color, in a manner to be briefly explained below. By coupling the concepts of radiative transfer theory to the C.I.E. color coordinate system, an accurate, quantitative basis for the description of color phenomena within the atmosphere and the sea is achieved, which for the purposes of the present discussion we shall call *colorimetric radiative transfer theory*. Our goal in this section is to outline the union of the two theories and indicate the nature of its applications.

The color phenomena within the domain of colorimetric radiative transfer theory are manifold: a precise description and prediction is possible of the blue of the sky and of the reds and golds of sunsets; of the onset and growth of the blue and purple hazes between distant mountains and a receding observer; the odd yellowing of mercury vapor street lamps with distance in strange blue fogs [177]; the conventional but ever pleasant sight of a reddish-orange rising moon; the yellowing and reddening of extremely shiny surfaces such as corrugated aluminum roofs and sidings seen through long paths of sight in the atmosphere; the sickening brown smear of smog smothering a city. In the underwater domain, the colorimetric radiative transfer phenomena are overpowered and dominated by the highly selective absorption of reds and violets (and their neighboring colors), resulting in a powerful filtering of all sky light into a blue-green residue of greater or lesser luminance that pervades almost all submarine scenes.